NASA CR 144726

FINAL TECHNICAL REPORT

PRECISION ATTITUDE DETERMINATION SYSTEM

13900-6016-RU-00 1 JULY 1974

PADS SYSTEM DESIGN AND ANALYSIS

(SINGLE-AXIS GIMBAL STAR TRACKER)

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Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

TRW
SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH, CALIFORNIA 90278

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TABLE OF CONTENTS

1.0 INTRODUCTION

TRW has conducted design and development of Precision Attitude Determination System (PADS) technology for NASA Goddard Space Flight Center (GSFC) under contract NAS5-21111. This report documents the feasibility evaluation of an evolutionary development for use of a single-axis gimbal star tracker from prior two-axis gimbal star tracker based system applications. Detailed evaluation of the star tracker gimbal encoder is also addressed.

The report provides a brief system description, including the aspects of tracker evolution and encoder evaluation. System analysis includes evaluation of star availability and mounting constraints for the geosynchronous orbit application, and a covariance simulation analysis to evaluate performance potential. Star availability and covariance analysis digital computer programs are included as Appendices.

2.0 SYSTEM DESIGN

The Precision Attitude Determination System (PADS) employs star trackers and gyros to determine inertial-referenced attitude to arc-second level accuracy. PADS system design employing a two-axis gimbal star tracker has been previously documented [1]. Key system design differences in employing a single-gimbal star tracker involve both hardware (e.g., tracker and associated electronics) and software. These differences and potential system design and performance tradeoffs are discussed in this section.

2.1 System Configuration/Definition

The PADS star tracker, electronics, gyros, and computer/software shown schematically in Figure 2-1, are functionally and operationally similar to previous design [1]. The single-gimballed Star Tracker Assembly (STA) is used to track stars and provide a measure of the star line-of-sight (LOS) angle. The Sensor Electronics Assembly (SEA) provides the gimbal servo/drive electronics and gimbal readout processing. The Gyro Reference Assembly (GRA) incorporates a configuration of strapdown pulse rebalanced rate integrating gyros plus electronics. A Reference Block Assembly (RBA) provides a stable thermo-mechanical interface with the spacecraft to which the sensors are mounted and aligned relative to each other. The Digital Processor Assembly (DPA) comprises the computer - I/O to implement system software.

The gyros provide high-bandwidth data which is compensated to account for systematic gyro errors and used to derive attitude. Attitude and gyro drift (bias) corrections are periodically estimated via star tracker measurements processed in a Kalman filter.

The gimballed tracker is operated to intercept defined stars of opportunity. The gimbal freedom is such as to provide a single axis of mechanical scan. The tracker is mounted in the spacecraft such that the FOV moves in a plane generally defined as normal to the orbit plane, with gimbal freedom chosen to assure adequate star sightings. Based upon a series of such

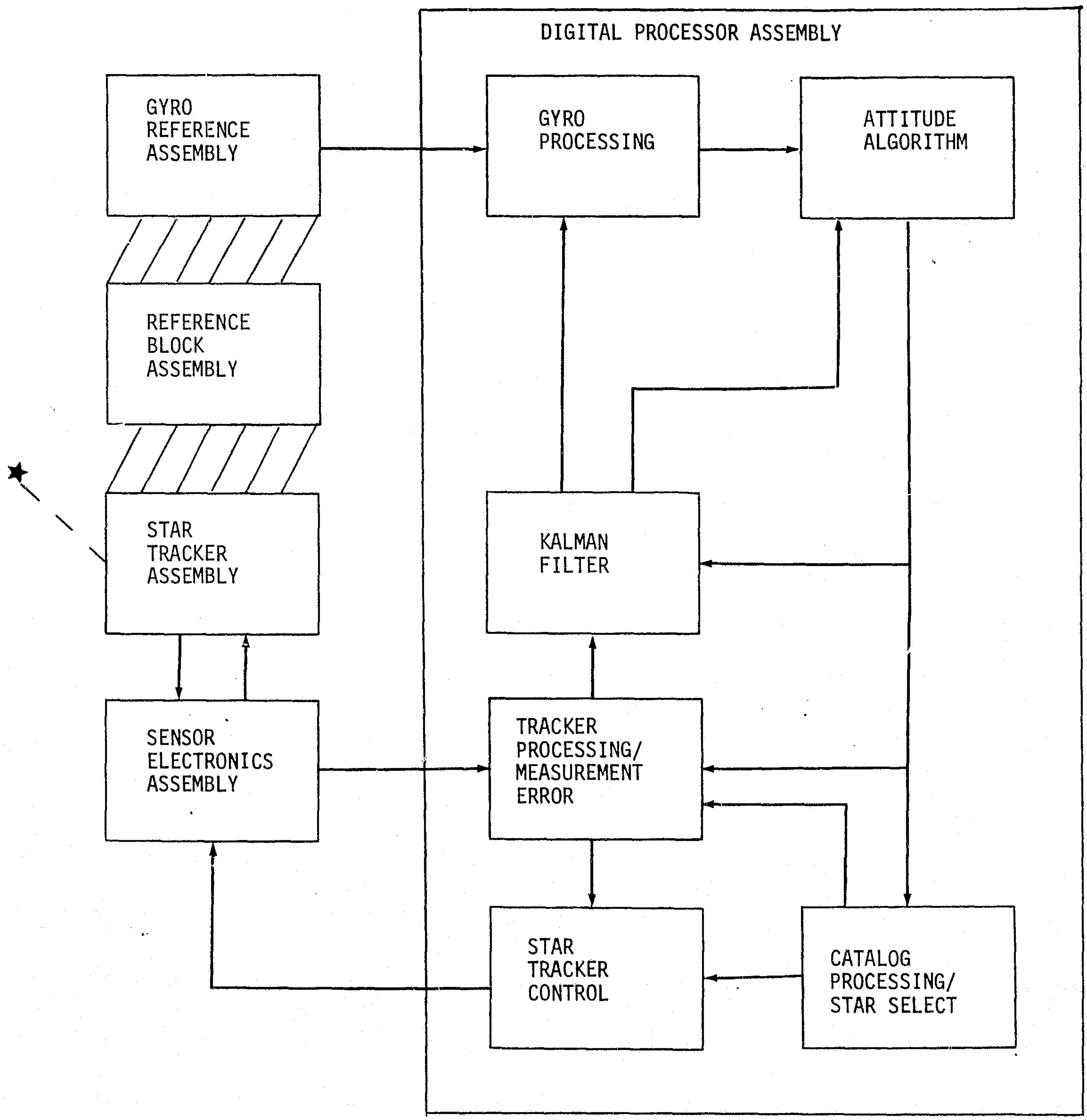


Figure 2-1. PADS Functional Block Diagram

sightings, the attitude estimate will converge to an accuracy consistent with system alignment and bias uncertainties; typically, steady-state is reached within 10 sightings or less. During this period, the system will reach thermal equilibrium. In-flight calibration may be utilized to determine compensation for systematic errors. Observables include gyro input axis misalignments, scale factor uncertainties, and tracker misalignments.

The configurated PADS system physical characteristics are summarized in Table 2-1. The single-axis gimballed tracker utilizes the identical Star Sensor Unit (SSU) and one-axis of the gimbal suspension/drive assembly of the two-axis tracker design [1]. Likewise, the Sensor Electronics Assembly is of identical design, although it again provides drive and readout electronics for only a single channel. Revised size, weight, and power characteristics have been derived accordingly.

2.2 Design Evaluation

Prior PADS star tracker development, although oriented toward a two-axis gimbal design, was limited in hardware development to a single-axis engineering model gimbal. This single-axis design is assumed used directly for the current PADS application. During the PADS star tracker development and test [2], however, problems with the encoding electronics were noted but not fully defined. In the following discussion, these problems are identified and design modifications recommended.

In testing the PADS system, certain anomalous behavior was noted in the breadboard Inductosyn angle encoding. Investigation was confined to the single speed channel, which was modified to read out all 14 available bits. There were three basic forms of anomaly as shown by the error curve in Figure 2-2.

(1) A wide-range cyclic error which appeared to be in excess of 2° peak-to-peak over the available 90° of gimbal travel.

Table 2-1. Summary of PADS Physical Characteristics

	Wt (lb)	Power (w.)	Envelope (in.)
Star Tracker Assembly (STA)*	26	7	9.6 x 20.0 x
Sensor Electronics Assembly (SEA)	4	8	6 x 8 x 4
Gyro Reference Assembly (GRA)(1)	9	10	6 x 6 x 5
Reference Block Assembly (RBA)	10	--	--
Digital Processor Assembly (DPA)(2)	17	27	11.5 x 10.5 x 6.5
Integration Hardware	4	--	--
Total System	70 lb	52 w	21" x 26" x 20"(3)

* Single-axis gimbal design
(1) Triad, Unheated
(2) Typical
(3) Approximate total envelope occupied

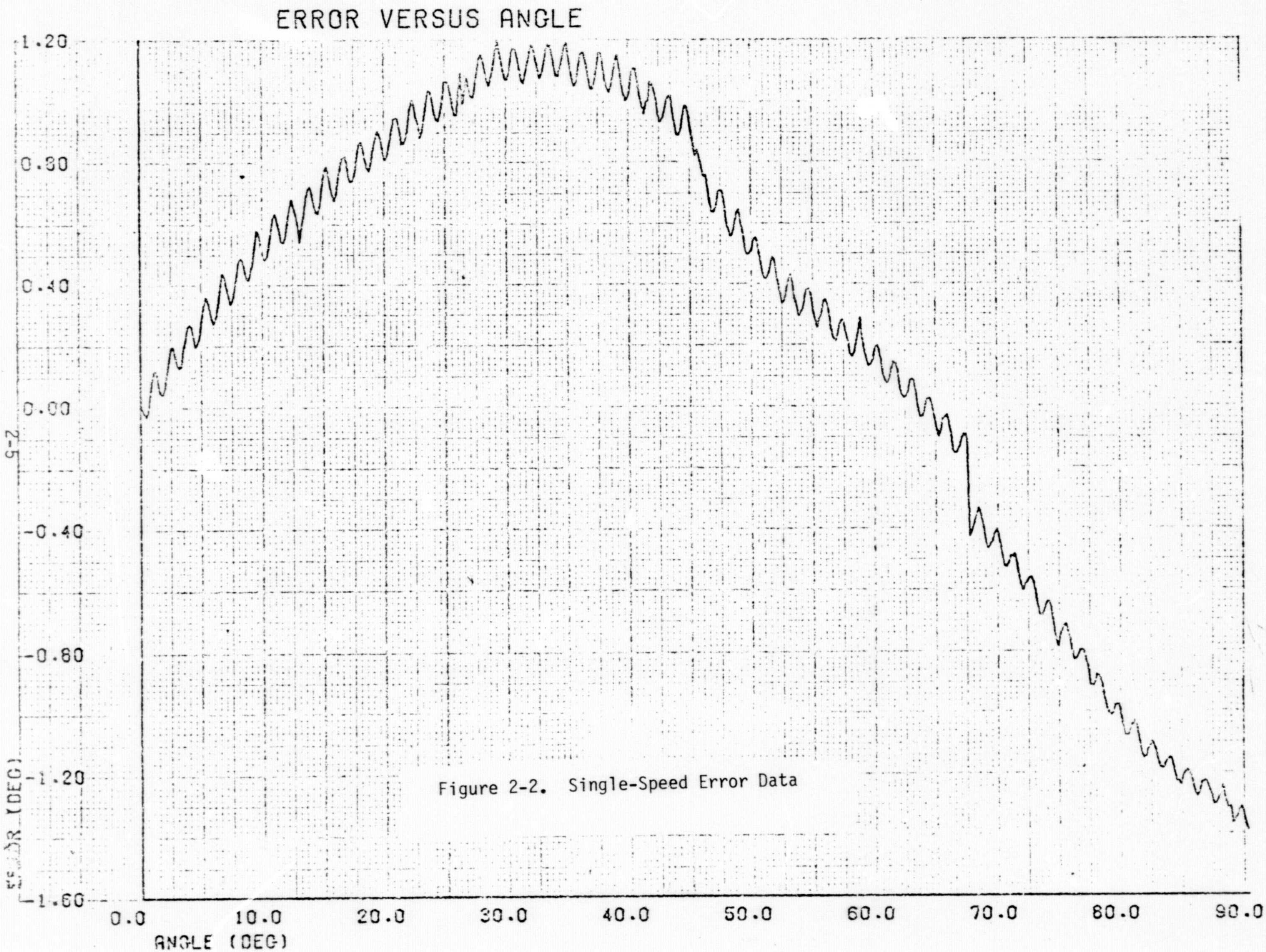


Figure 2-2. Single-Speed Error Data

(2) A fine-scale cyclic spatial modulation of the error function, with amplitude approximately 0.1° and periodicity about 1.4°.

(3) Noise in the output data of about 4 bits peak-to-peak.

The investigation of these problems was initiated, with emphasis on diagnosis. The system was set up, including the SEA breadboard, the gimbal, and the test set. An optical cube mounted on the Star Tracker case permitted the use of a T3 autocollimator. A rotary table enabled rotation of the gimbal base with a resolution in the region of a fraction of a minute, the gimbal being manually counter-rotated to the Autocollimator null for each table setting. Note that because the original null is relatively arbitrary, accuracy is here to be understood in the sense of linearity. Absolute accuracy (bias) depends on the initial Inductosyn mechanical alignment in rotation, and on total system stability thereafter. As a first step, the test findings were essentially verified in all three respects: a gross nonlinearity, a fine-scale linearity ripple, and excessive output data jitter of about 16 counts.

The spatial ripple error was suspected to be due to stray coupling from the 256-speed channel because of its periodicity. The amplitude-to-phase breadboard was a poor layout, with a considerable amount of physical interleaving of the single-speed and multi-speed elements. To check this, all the integrated circuits of the multi-speed channel were removed, although the preamps were left operating. The ripple error was reduced from about 0.1° peak-to-peak to a value indiscernable under existing conditions.

The wide-range error was tracked to a miswired capacitor in the amplitude-to-phase converter. Correction of this yielded a linearity error of approximately 0.5 degree peak-to-peak (Figure 2-3). This is similar to the Farrand data for the single-speed Inductosyn, although the shape of the developed error curve cannot be matched with that for the Inductosyn because of unavailability of Farrand's definitions of electrical zero, positive angular rotation, and positive error.

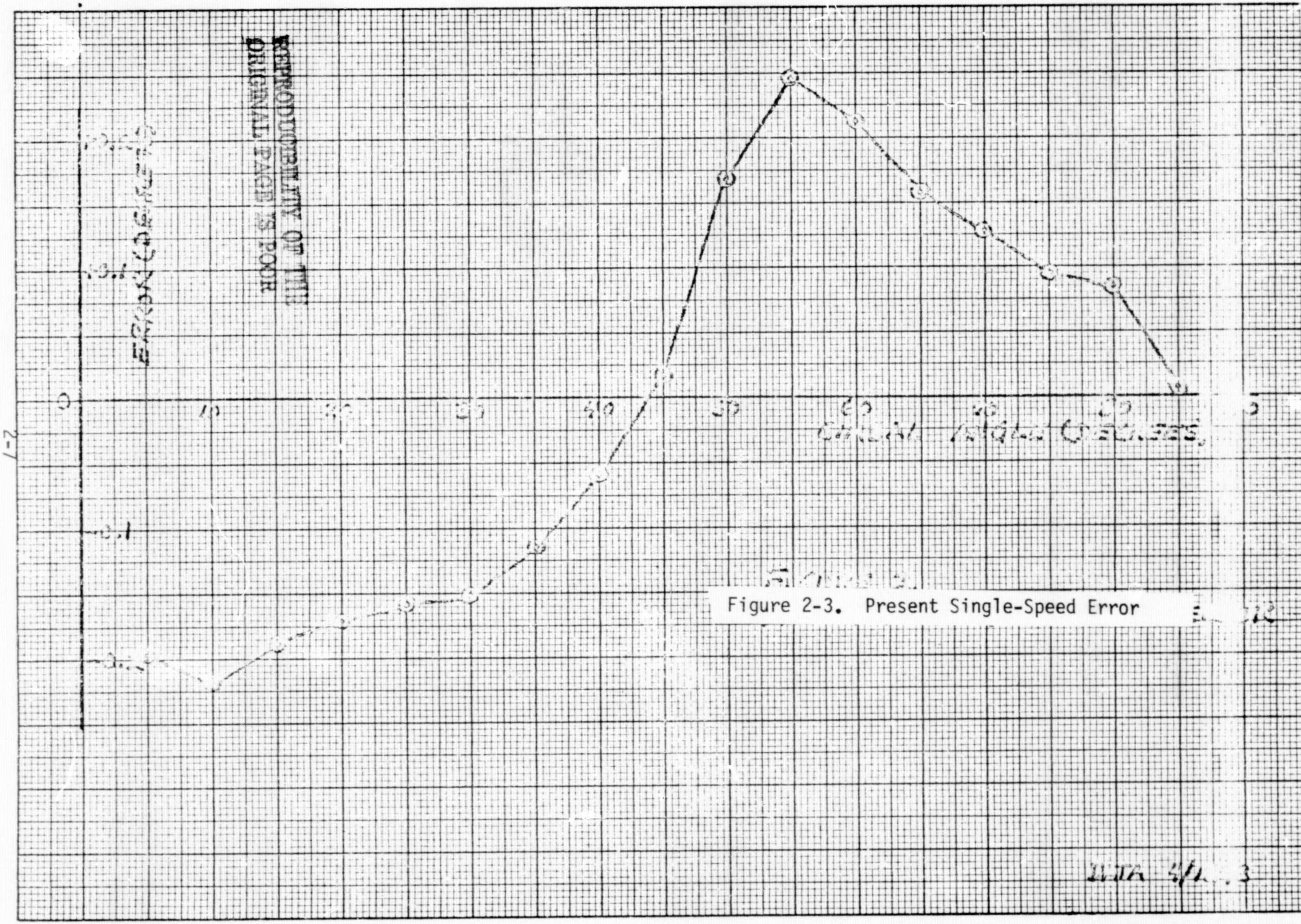


Figure 2-3. Present Single-Speed Error

In an attempt to characterize the noise behavior, random data samples at a given gimbal angle were recorded and plotted. A typical histogram of 100 samples is shown in Figure 2-4. The horizontal quantization is one least-significant count, 2^{-14} of an electrical revolution. In the 256-speed channel, a quanta would be 0.309 arc-seconds.

The analog processing chain, consisting of the Preamplifiers, the Buffers, and the Amplitude-to-Phase Converters appears to be generating AM noise. This chain has a relatively high gain and uses μA715's, which are not notable as low-noise devices. This AM noise in the sinusoidal phase signals would be mapped into phase noise by the Zero-Crossing Detectors. A scope examination of these signals did indeed show some 200 to 300 ns of phase jitter of the logic transitions of the lag signal with respect to the lead.

To check this, a passive RC phase-shifting network was constructed and excited directly with the excitation voltage, so as to give two sinusoidal outputs, one slightly lagging the other. These were fed directly to the Zero-Crossing Detectors, bypassing the analog front-end elements. The phases were now extremely stable, but the encoded output data was still quite noisy.

To obtain a noise comparison, the output data was D-A converted and the result displayed on a scope and photographed with a slow sweep. Figure 2-5 illustrates the resultant noise indication. Each dot represents a successive data sample. Each row of dots is associated with a distinct data quantization level of one least significant (2^{-14}) unit.

The data for the "noiseless" phase-shifter appears to have a width of 16 quanta and a relatively sharp-peaked distribution. That for the normal system has width about 20 quanta wide and a somewhat broader distribution peak.

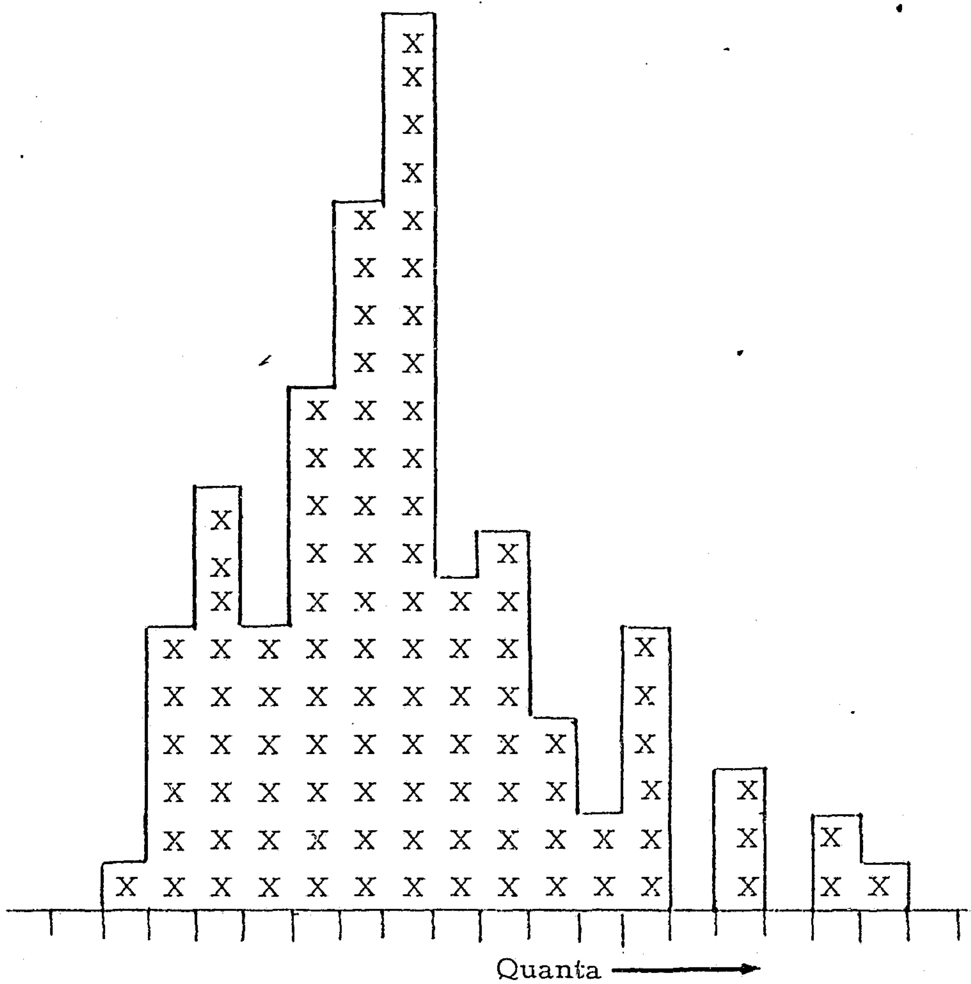
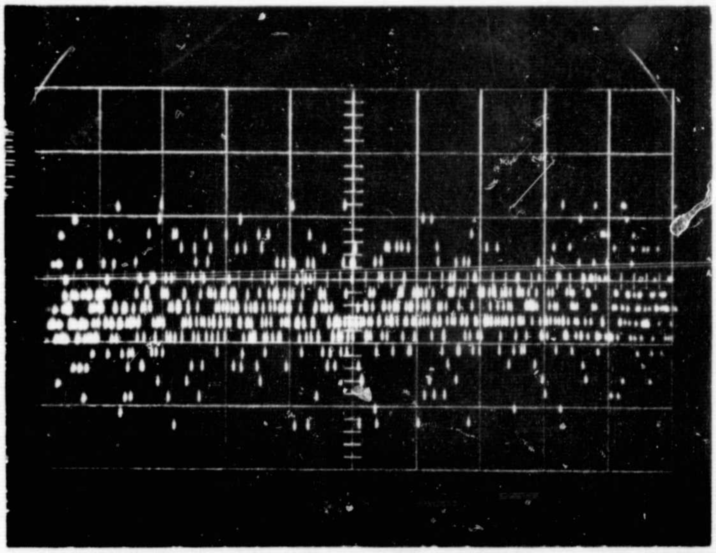
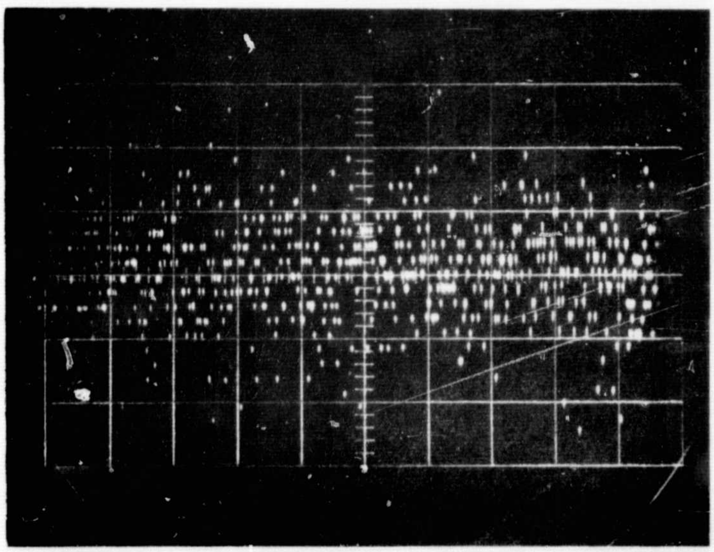


Figure 2-4. Typical Data Noise Histogram



Passive Network
("Noiseless" Phase-Shifter)



Normal System

Figure 2-5. Encoding Data Noise

Vertical: 20 MV/CM
Horizontal: 0.2 Sec/CM

The conclusion must be that there is a second noise source associated with the encoding process itself. That was tracked to the VCO within the Excitation Section. In order to obtain 2^{14} resolution with a moderately high (∿10 kHz) excitation frequency and a manageable clock frequency (2.8 mHz), phase determination is done over 15 excitation cycles. The excitation is generated as 15/2048 of the clock frequency. This has the effect of lining up the clock pulses in successive excitation cycles, as illustrated in Figure 2-6. Each excitation cycle contains 273 1/15 clock pulses, leading to the 1/15 precession shown.

A phaselock loop is used to obtain the integer 15 portion of the excitation-to-clock frequency relationship. Considerable short-term phase jitter was observed in the VCO output. The phenomenon of output data noise due to this can be related as follows. Consider the vertical lines in Figure 2-6 to represent a time gate which admits clock pulses to a counter. As shown, the gate opens and closes at precisely the same phase each excitation cycle. A count of one or zero might be registered depending on the arbitrary choice of mean phase.

Widening the gate with the same mean phase would represent the result of Inductosyn rotation. A random phase jitter of both gate edges, with respect to one another from cycle to cycle would represent the result of the phase noise previously described. There would be a corresponding variation in the count from one block of 15 cycles to another.

Now assume that the gate width remains precisely constant, as would be the case for the passive network, but that its mean position jittered randomly from cycle-to-cycle. It is likely that at times it could sweep along at just the proper rate to gather up 15 clock pulses. At other times, it might intersect none. At still other times it may sweep up some intermediate number.

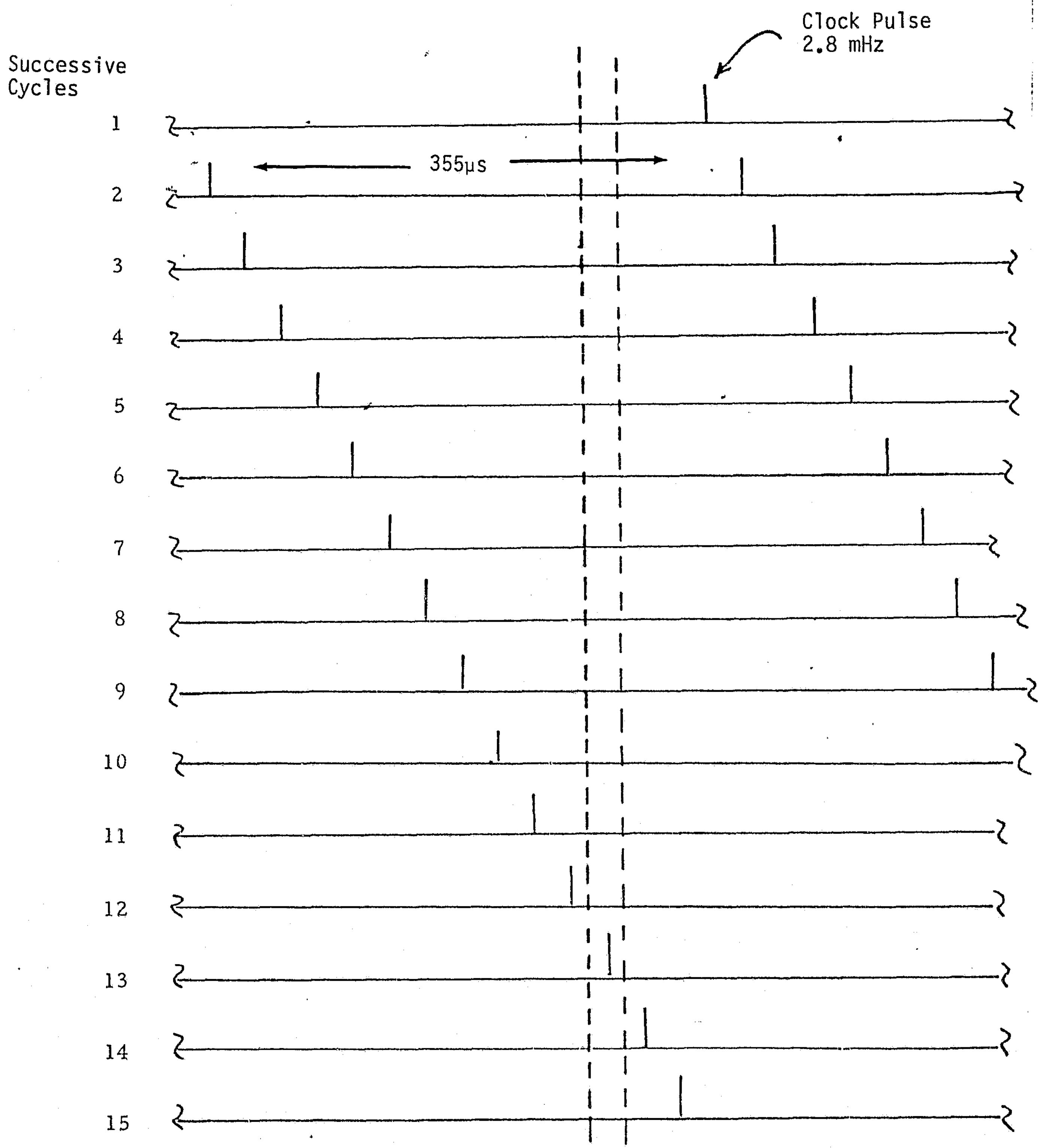


Figure 2-6. Clock Phases in Successive Excitation Cycles

Hence, with a completely "noiseless" analog processing front end, but a phase-jittering excitation, noise is still possible. This phenomenon is a hazard peculiar only to multi-cycle encoding, since a single-cycle encoder would not use a phaselock loop.

Basically, the PADS encoding technique appears to have been rather successful. During design, it was necessary to make certain practical compromises in the interests of working out and demonstrating the basic concepts. Primary stress was placed on accuracy. This is still not assessed because of our present inability to subtract the Inductosyn errors. But even if one assigns the whole ±0.2 degree linearity error of Figure 2-3 to the electronics alone, this is equivalent to ±3 arc-seconds at the multi-speed level. This could probably be improved to the ±1 arc-second vicinity.

Little attention was paid to circuit shielding in PADS, partly because of its expense, but mostly because of the desirability of exposed circuitry in a developmental effort. It seems that a packaging style using a number of enclosed shielding compartments will be necessary for the analog front-end elements, at least for the multi-speed channels.

Noise performance tended to be ignored in the PADS design. The choice of the μA715 for the front end elements was dictated by a desired for a wide bandwidth. Gain precision, and hence large excess gain at 10 kHz, is essential to accuracy. This device is not characterized for noise. Newer amplifiers are available with reasonable bandwidths and noise characterizations. Although they do not have the amount of open-loop 10 kHz gain, it is possible that a more judicious gain distribution can be used.

The requirement for a very quite phaselock loop was unsuspected, partly because of the subtlety of the noise phenomenon previously described. Future design will probably require a crystal VCO.

The present noise performance of the PADS gimbal readout appears to be of the order of ±8 to 10 quanta, corresponding to ±2.5 to 3 arc-seconds, multi-speed. Assuming that this is composed of approximately equal parts of

analog front-end noise and VCO noise, that the front-end noise could be reduced by 5 using quieter amplifiers, and that the VCO noise could be eliminated by using a crystal VCO, it is likely that the noise performance could be reduced to the order of ±1.4 quanta, a fraction of an arc-second. Note, however, that this estimate is made without consideration for those sorts of non-linear sampling effects which may occur when noise and quantization approach each other.

Evolution of the PADS software for the single-gimbal tracker system is limited to those elements which relate to models, measurement, and control of the star tracker. All other software remains unchanged. Thus the only elements effected are the catalog processing (star sort, selection), computation of the measurement residual, and derivation of the measurement matrix. The catalog processing reflects logic to acquire and track stars of opportunity (rather than at periodic intervals), and the measurement related algorithms previously derived are, in this case, constrained by the assumption of zero outer gimbal angle.

3.0 SYSTEM ANALYSIS

3.1 Star Availability Analysis

Assessment was made of the tradeoffs in geometry and mounting constraints for use of the existing single-gimbal tracker in geosynchronous orbit application. The key tracker constraints that must be satisfied include:

- Star magnitudes brighter than $m_V = +3.5$
- Tracker gimbal freedom $\leq \pm 60$ degrees
- Sun avoidance angle of 45 degrees

From a spacecraft systems application standpoint, certain other constraints and/or design guidelines were established, viz.

- Only one single-gimbal tracker need be active
- Minimize FOV geometry interface requirements
- Configuration well suited to operation during all times of year

A star availability digital computer program was developed which orders stars (by orbit angle) in sequence of observation as constrained by the gimbal FOV. The orbit angle between successive star sightings becomes a measure of star availability. The digital program (Appendix A) includes specification of orbit parameters, tracker performance and mounting parameters, and input from a separate master star catalog file. Table 3-1 summarizes the results of a series of computer runs.

From the tabulated results, it appears that the best mounting geometry is for the nominal boresight (zero-gimbal angle) to be directed at one of the two poles. This minimizes the effects of sun interference (greatest for boresight N in summer, for boresight S in winter). Some flexibility in star mounting and selection appears achievable. Although choice of ±45° gimbal

Table 3-1. Single-Axis Gimbal Tracker Star Availability
(Geosynchronous Orbit)

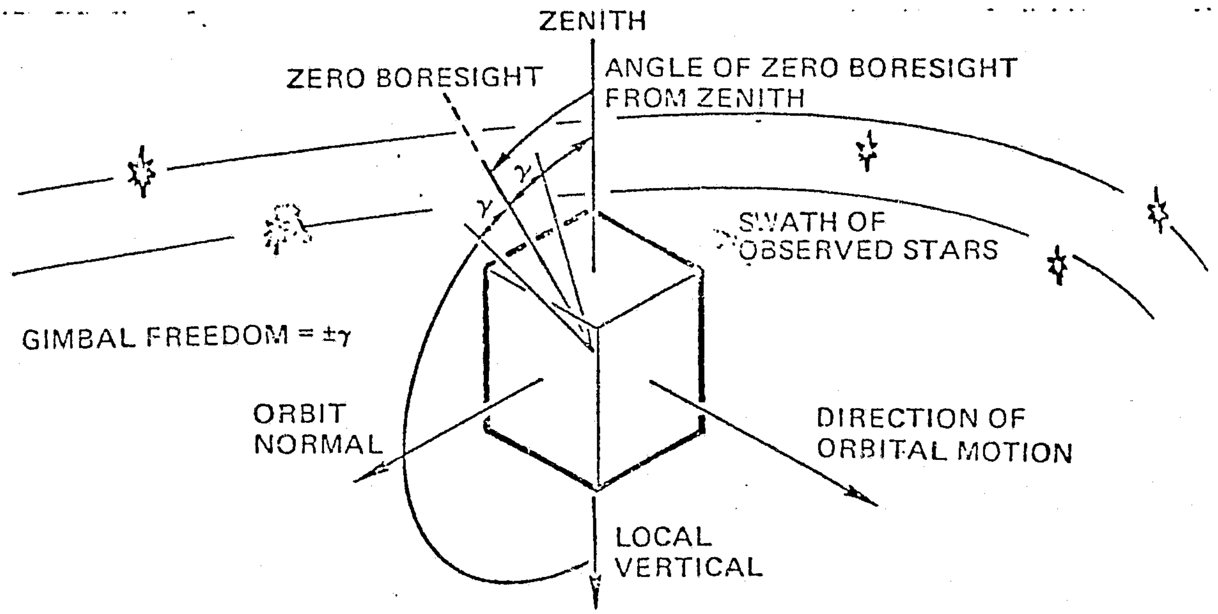
Boresight Mounting	Star Magnitude (minimum)	Gimbal Freedom (deg)	Time of Year Evaluated	Results/Comments
Zenith	3.5			Significant sun interference problem, particularly near equinoxes
45°N	3.5	30	Spring/ Summer	Spring - 69 stars, gap of 40° (about sun) Summer - 53 stars, gap of 119° (about sun)
45°N	3.5	45	Spring/ Summer	Spring - 86 stars, gap of 40° Summer - 67 stars, gap of 106°
N	3.5	45	Spring/ Summer	Spring - 58 stars, maximum gap of 27° Summer - 48 stars, maximum gap of 27°
N	3.5	60	Summer	74 stars, few scattered gaps of 12-15°
N	4.0	45	Summer	78 stars, scattered gaps of 10-12°
45°S	3.5	30	Winter	80 stars, maximum gap of 75° (about sun), other scattered gaps of 10-22°
45°S	3.5	45	Winter	96 stars, maximum gap of 71° (about sun), other scattered gaps of 10-22°
S	3.5	30	All	40 stars, scattered gaps of 10-23°
S	3.5	45	Spring	104 stars, scattered gaps of 10-17°

freedom appears reasonable, opening the freedom to ±60° improves performance potential whereas reduction to ±30°, while potentially degrading performance somewhat, minimizes spacecraft FOV constraints. It was also noted that selection of slightly dimmer stars (e.g., $m_V = +4.0$) did, in fact, somewhat increase performance potential.

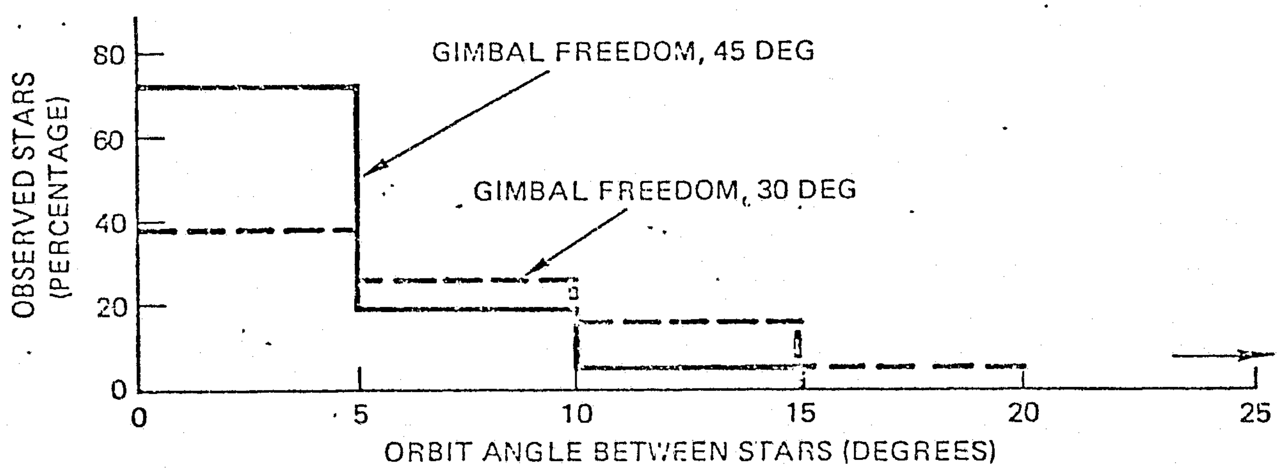
Figure 3-1 is a histogram which summarizes tradeoffs for cases of boresight South. A baseline system configuration is selected with the boresight South and gimbal freedom of ±45 degrees. In geosynchronous orbit, 15 degrees of orbit motion corresponds to an hour. Thus, the worst case time between stars for the given orbit will be somewhat greater than one hour.

3.2 Error Analysis

PADS using a single-axis gimbal tracker will have performance characteristics which differ somewhat from a system using a two-axis gimbal tracker. This comes about primarily from the imposed limitation to utilize stars of opportunity rather than being able to seek stars at periodic (arbitrary) intervals. As a result, performance becomes more dependent upon gyro behavior, since updates will not be available as often (as noted through the star availability analysis of the preceding section). TRW, in recognizing this, has done considerable work in the modelling and analysis of gyro reference systems [3], results of which may be applied directly. This section summarizes the system and component errors - the system error budget is outlined in Table 3-2. The star tracker errors and gyro data for drift and bias uncertainty are based upon data and models developed in the sections which follow. Gyro alignment and scale factor errors assume the full uncertainty is realized with a uniform rate of change over 20 minutes. The average update period of 20 minutes implicit in the results for gyro error is consistent with the star availability in the preceding section. The RSS of these error sources betters the goal of 0.001 degree (= 3.6 arc-second), 1σ, per axis.



SUMMARY OF REPRESENTATIVE CASES* GEOSYNCHRONOUS ORBIT, ZERO BORESIGHT SOUTH (ALONG ORBIT NORMAL)



* DATA AVAILABLE FOR MANY CASES. INDIVIDUAL STARS AND PERIOD BETWEEN SIGHTING IDENTIFIED.

Figure 3-1

Table 3-2. System Error Budget
(Single-Gimbal Tracker)

ERROR SOURCE/BUDGET			CONTRIBUTION (1σ, per axis)
STAR TRACKER			
BIAS	,	0.44 $\widehat{sec}$ (1σ)	0.44 $\widehat{sec}$
RANDOM	,	1.31 $\widehat{sec}$ (1σ)	1.31 $\widehat{sec}$
NOISE	,	1.2 $\widehat{sec}$	1.2 $\widehat{sec}$
		SUBTOTAL, RSS	1.83 $\widehat{sec}$
GYRO REFERENCE			
RANDOM DRIFT	,	< 2 $\widehat{sec}$ over 20 Minutes	2 $\widehat{sec}$
BIAS UNCERTAINTY	,	0.001^{o}/Hr	1.2 $\widehat{sec}$
ALIGNMENT STABILITY	,	10 $\widehat{sec}$	0.45 $\widehat{sec}$ (1)
SCALE FACTOR STABILITY	,	100 ppm	0.9 $\widehat{sec}$ (1)
PULSE QUANTIZATION	,	0.01 $\widehat{sec}$	-
		SUBTOTAL, RSS	2.54 $\widehat{sec}$
COMPUTATION			1.0 $\widehat{sec}$
		TOTAL, RSS	3.29 $\widehat{sec}$

(1) Based upon uniform change over 20 minutes

3.2.1 Star Tracker Errors

The star tracker errors have been derived from analysis and test data associated with the single-gimbal engineering model tracker [2]. The tracker and electronics errors are summarized in Table 3-3.

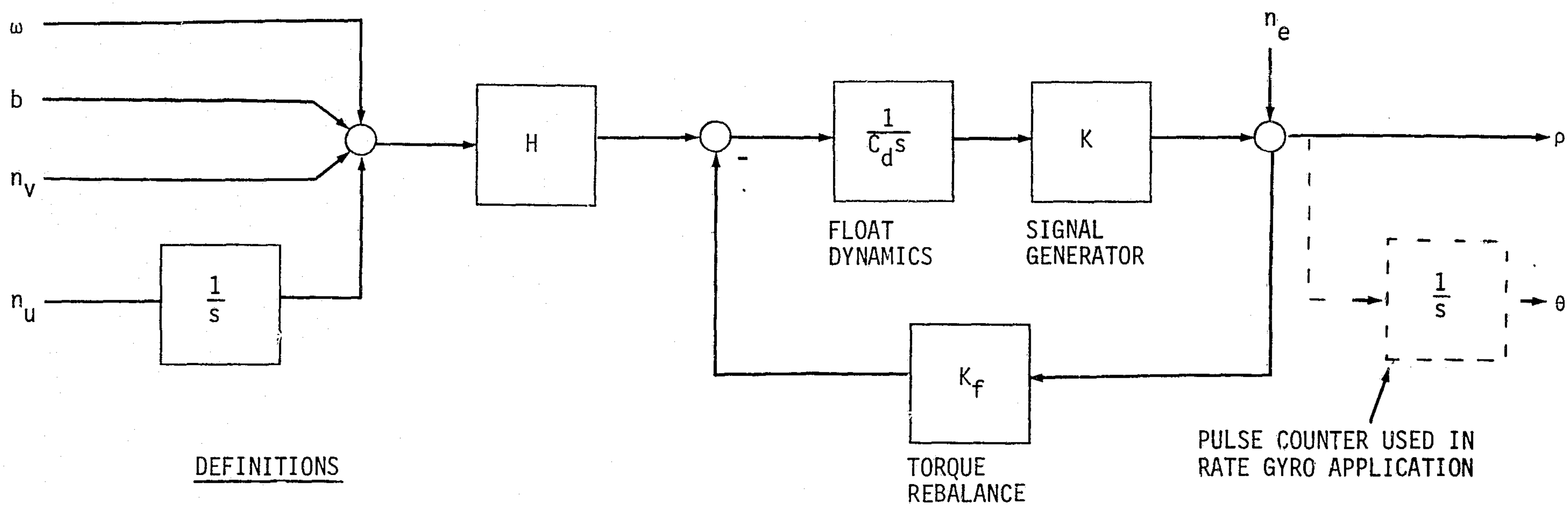
3.2.2 Gyro Errors

The development of gyro errors is based upon a gyro model having the characteristics as shown in Figure 3-2. The input axis rate, ω, is gyroscopically converted to a torque acting upon the viscously damped float. Angular motion of the latter about the gyro output axis is converted by the signal generator to an electrical output whose average value is essentially linear with respect to float motion. This output might simply be a continuous analog signal; or else a train of frequency modulated pulses, with the pulse rate dependent upon the float motion. The gyro electrical output is fed back to a magnetic torquer in order to rebalance the float. As indicated in Figure 3-2, appropriate selection of the gyro parameters usually results in either a rate gyro or a rate-integrating gyro. The former are generally characterized by fairly high bandwidths (e.g., 5 Hz or so) whereas the latter employ low bandwidths (e.g., 0.004 Hz) in order to effect their integration process. Clearly, in order to obtain angular outputs with a rate gyro, an additional integration must be performed. With frequency modulated pulse signal generators, this integration is easily accomplished for PADS by use of a counter whose contents are read and reset to zero each integration period, e.g., 200 ms. Thus the gyro output used for PADS is a measure of the incremental change in angle measured about the gyro input axis over the (short-term) integration interval.

Three basic uncorrelated gyro error sources have been postulated. Electronic noise can exist at the signal generator input (or equivalently, its output). Additionally, the various gyro mechanical imperfections give rise to a torque noise, n_v/H, acting directly upon the gyro float. Both these noise sources will be assumed zero mean and white. The fact that some self-correlation does exist in these noise sources is of little consequence

Table 3-3. Single-Gimbal Star Tracker and Electronics Error Characteristics

SENSOR		
Electronic (Bias)	.14	arc-sec
Thermal-Mech (Random) (30°C Range)	.46	arc-sec
Noise Equivalent Angle	.2	arc-sec
GIMBAL AND ENCODER		
Gimbal Alignment (Random)		
Runout	.5	arc-sec
Perpendicularity	.5	arc-sec
Gimbal Thermal-Mech (Random)		
Stress Relaxation	.2	arc-sec
Thermal	.2	arc-sec
Inductosyn (Random)		
θ	.7	arc-sec
256 θ	.5	arc-sec
READOUT ELECTRONICS		
Bias		
Zero Crossing Offset	.13	arc-sec
Phase Stability	.4	arc-sec
Random		
256 θ Excitation Harmonics	.27	arc-sec
512 θ		
Cross Coupling	.27	arc-sec
Gain Unbalance	.13	arc-sec
A-θ Converter	.13	arc-sec
Noise-Quantization	0.3	arc-sec



DEFINITIONS

H = GYRO ROTOR MOMENTUM
C_d = GYRO DAMPING CONSTANT
K = SIGNAL GENERATOR GAIN
K_f = TORQUE REBALANCE GAIN
ω = GYRO INPUT RATE
b = FIXED GYRO DRIFT RATE
ρ = GYRO OUTPUT
θ = INTEGRAL OF GYRO OUTPUT FOR RATE GYROS
τ_g = C_d/KK_f
n_e = WHITE SIGNAL GENERATOR NOISE
n_v = WHITE FLOAT TORQUE NOISE/H
n_u = WHITE TORQUE DERIVATIVE NOISE/H

RATE GYRO: $K_f = H$, $\tau_g << 1$

RATE INTEGRATING GYRO: $K = C_d/H$, $\tau_g >> 1$

$$E[n_i(t)] = 0 \qquad E[n_i(t_1)n_j(t_2)] = \begin{cases} \sigma_i^2\ \delta(t_1-t_2);\ j=i \\ o;\ j \neq i \end{cases}$$

$$i,j = e,v,u$$

Figure 3-2. Block Diagram of Gyro Model and Definition of Parameters

as their bandwidths normally extend far beyond that of the gyro loop itself. Finally, there exists a gyro drift rate bias, by far the most significant error source unless appropriately compensated. While it is tempting to suppose that this drift rate holds constant at some value, b, it must be recognized that this bias may, itself, vary over the long time intervals normally encountered in attitude determination applications due to thermal and other effects. The model treats the drift rate as a random walk process, biased to the value b at some initial time, and wandering thereafter as a result of the zero mean white noise influence, n_u. The fact that this drift rate model implies an unbounded gyro output variance with time is of little concern here, as $|n_u|$ is numerically so small that for the typical time intervals indicative of attitude determination applications, a realistic drift behavior is indicated. Experimental justification of this entire gyro model is demonstrated at a later point.

The characteristics of the integral of rate gyro output is summarized in Table 3-4. Noting the definitions introduced in Figure 3-2, Table 3-4 shows how the integrated rate output, θ, depends upon the various error sources previously discussed. Transfer functions are first presented relating these outputs to the error sources; and then the output standard deviation of each error is shown. Letting "E" denote expectation and g(t), the pertinent transfer function impulse response, the standard deviations were computed by noting that

$$\sigma_\theta^2(t) = E\left[\theta^2\right] = E\left\{\left[\int_0^t n_i(\tau) g\,(t-\tau)d\tau\right]\left[\int_0^t n_i(\lambda) g\,(t-\lambda)d\lambda\right]\right\}$$

$$= \int_0^t g(t-\tau)\left[\int_0^t E\left[n_i(\tau)n_i(\lambda)\right]\, g(t-\lambda)d\lambda\right] d\tau = \sigma_i^2 \int_0^t g^2(t-\tau)d\tau$$

$$(i = e, v, u)$$

Table 3-4. Characteristics of the Integral of Rate Gyro Outputs

GYRO ERROR SOURCE	OUTPUT TRANSFER FUNCTION TO NOISE SOURCE	OUTPUT STANDARD DEVIATION AT TIME t	
		$\tau_g > 0$	LIMIT AS $\tau_g \to 0$ (IDEAL RATE GYRO)
WHITE FLOAT TORQUE NOISE/H	$\frac{1}{s}\left[\frac{1}{\tau_g s+1}\right]$	$\sqrt{\frac{\tau_g}{2}}\left[2\left(\frac{t}{\tau_g}\right)-\left(1-e^{-t/\tau_g}\right)\left(3-e^{-t/\tau_g}\right)\right]^{1/2}\sigma_v$	$\sigma_v t^{1/2}$
DRIFT RATE DERIVATIVE FLOAT TORQUE NOISE/H	$\frac{1}{s^2}\left[\frac{1}{\tau_g s+1}\right]$	$\tau_g^{3/2}\left[\frac{1}{3}\left(\frac{t}{\tau_g}\right)^3-\left(\frac{t}{\tau_g}\right)^2+\left(\frac{t}{\tau_g}\right)+\frac{1}{2} -2\left(\frac{t}{\tau_g}\right)e^{-t/\tau_g}-\frac{1}{2}e^{-2t/\tau_g}\right]^{\frac{1}{2}}\sigma_u$	$\frac{\sigma_u t^{3/2}}{\sqrt{3}}$
WHITE SIGNAL GENERATOR NOISE	$\frac{\tau_g}{(\tau_g s+1)}$	$\sqrt{\frac{\tau_g}{2}}\left[1-e^{-2t/\tau_g}\right]^{\frac{1}{2}}\sigma_e$	0
UNCERTAINTY IN THE DRIFT RATE BIAS AT t=0	$\frac{1}{s(\tau_g s+1)}$	$\left[t-\tau_g(1-e^{-t/\tau_g})\right]\sigma_b$ †	$\sigma_b t$

† σ_b is the standard deviation of the gyro bias uncertainty at t=0

Note that only the signal generator noise in the rate gyro integral application results in a stationary process. This is because the noise is high pass filtered by the gyro loop dynamics, and thus the gyro output has zero noise power density at d.c.

Assuming the rate gyro time constant to be small but finite, the separate effects of Table 3-4 can be root-sum-squared to yeild the dependence of the output standard deviation, σ_θ, to all the error sources:

$$\sigma_\theta = \left[\frac{\tau_g \sigma_e^{\,2}}{2} + \sigma_v^{\,2} t + \sigma_b^{\,2}\, t^2 + \frac{1}{3}\sigma_u^{\,2}\, t^3 \right]^{\frac{1}{2}}$$

It is seen that $\sigma_\theta^{\,2}$ contains terms dependent upon t^0, t^1, t^2, and t^3. It will be later observed that a minimum limit in σ_b, dependent upon σ_v and σ_u, exists if the drift rate bias is to be calibrated using the Kalman filter estimation.

Figure 3-3 illustrates the results of data taken on two gas bearing gyros typically used in attitude determination applications - the Nortronics K7G and the Honeywell GG334. Fixing a specific sampling (or integration) time, t, the standard deviation σ_θ, of a large number of samples (with the drift rate bias removed) was experimentally established. This was done for integration times ranging from 0.1 second to 10^6 seconds. It can be seen that Figure 3-3 supports the model which was derived. For $0.1 < t \leq 10$ seconds, the data indicates no strong time dependency and thus can be characterized as signal generator noise. For $10 < t \leq 2000$ seconds, the slope of the data on this log-log plot is about 1/2, indicative of the noise source n_v. As the sampling interval increases, the slope grows more steep, until finally it reaches 3/2, matching that of the drift rate variation noise source, n_u. The analytical model derived for the data of Figure 3-3 is expected to improve with use of current gyros. For example, based upon limited data, $\sigma_v = 0.015$ appears a good choice for the Bendix 64-PM-RIG gyros.

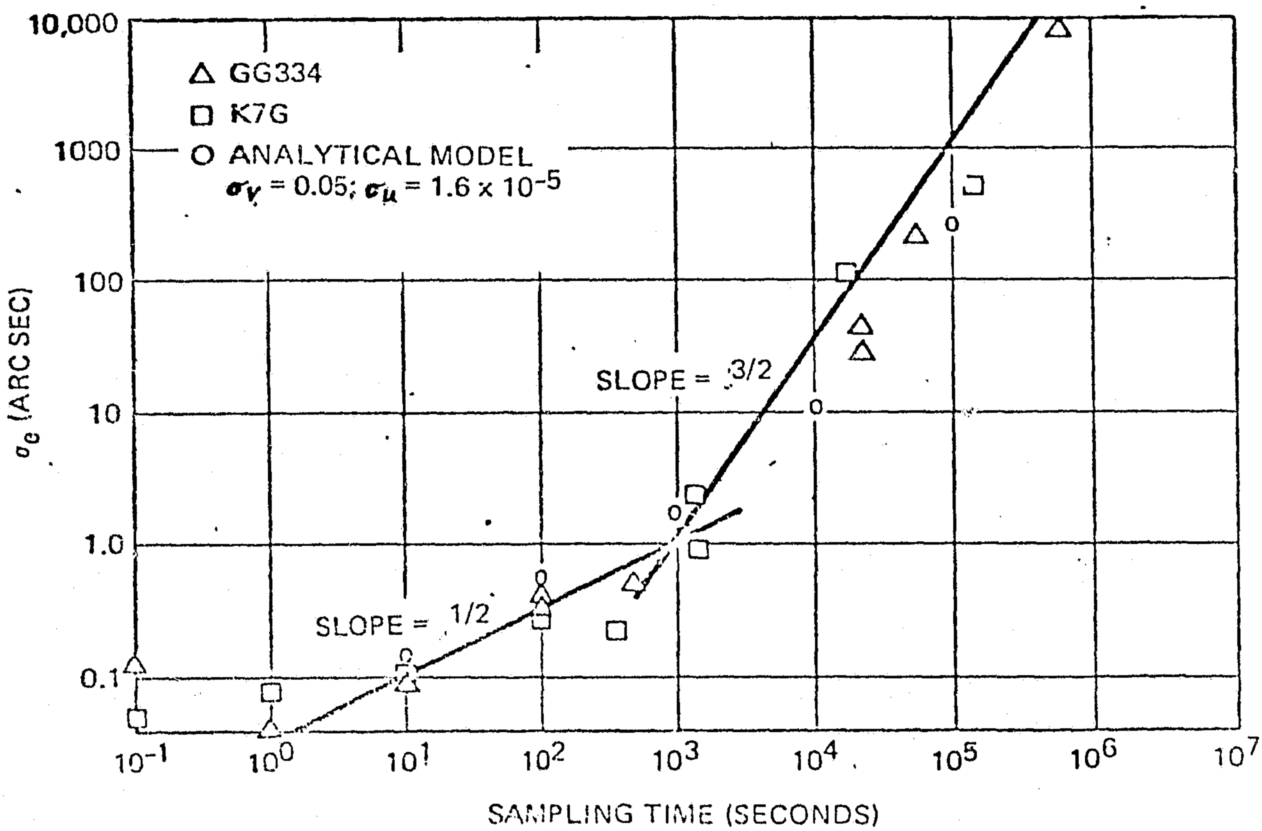


Figure 3-3. Test Data and Modelled Gyro Characteristics

Performance tradeoff curves were derived which relate the modelled gyro performance to the (attitude and gyro bias) estimation process. Error is normalized to (attitude update) sensor random noise. Figure 3-4 is a series of curves for estimated bias including gyro performance representative of the state of the art. Typically, $0.1 \leq S_v \leq 1.0$ and $0.05 \leq S_u \leq 0.5$ for $1\ \widehat{\sec} \leq \sigma_n \leq 5\ \widehat{\sec}$ and update period of 10-20 minutes. Estimates of gyro bias are on the order of 0.002 degree/hour - limited by the (ideal) case of a perfect attitude sensor:

$$\sigma_b = \sqrt{\sigma_u} \left[\sigma_v^2 + \frac{\sigma_u^2 T^2}{12}\right]^{\frac{1}{4}}$$

3.3 Covariance Analysis

A PADS covariance analysis digital computer program was developed to evaluate PADS performance using the single-gimbal star tracker. The covariance analysis establishes a lower bound on performance under the essential assumption that the statistical models employed in the Kalman filter accurately represent the real world.

3.3.1 Equation Development

The equations are developed to establish the covariance associated with estimation of attitude and gyro bias. Thus the state vector, $\overline{x}$, comprises three attitude variables (e.g., θ_i) and three gyro biases. The state error covariance, $E[xx^T]$, is propagated according to the Kalman filter equations:

$$S_{j+1} = \Phi_{j+1} P_j \Phi_{j+1}^T + Q_{j+1}$$

$$K_{j+1} = S_{j+1} M_{j+1}^T \left\{M_{j+1} S_{j+1} M_{j+1}^T + R_{j+1}\right\}^{-1}$$

$$P_{j+1} = \left[I - K_{j+1} M_{j+1}\right] S_{j+1}$$

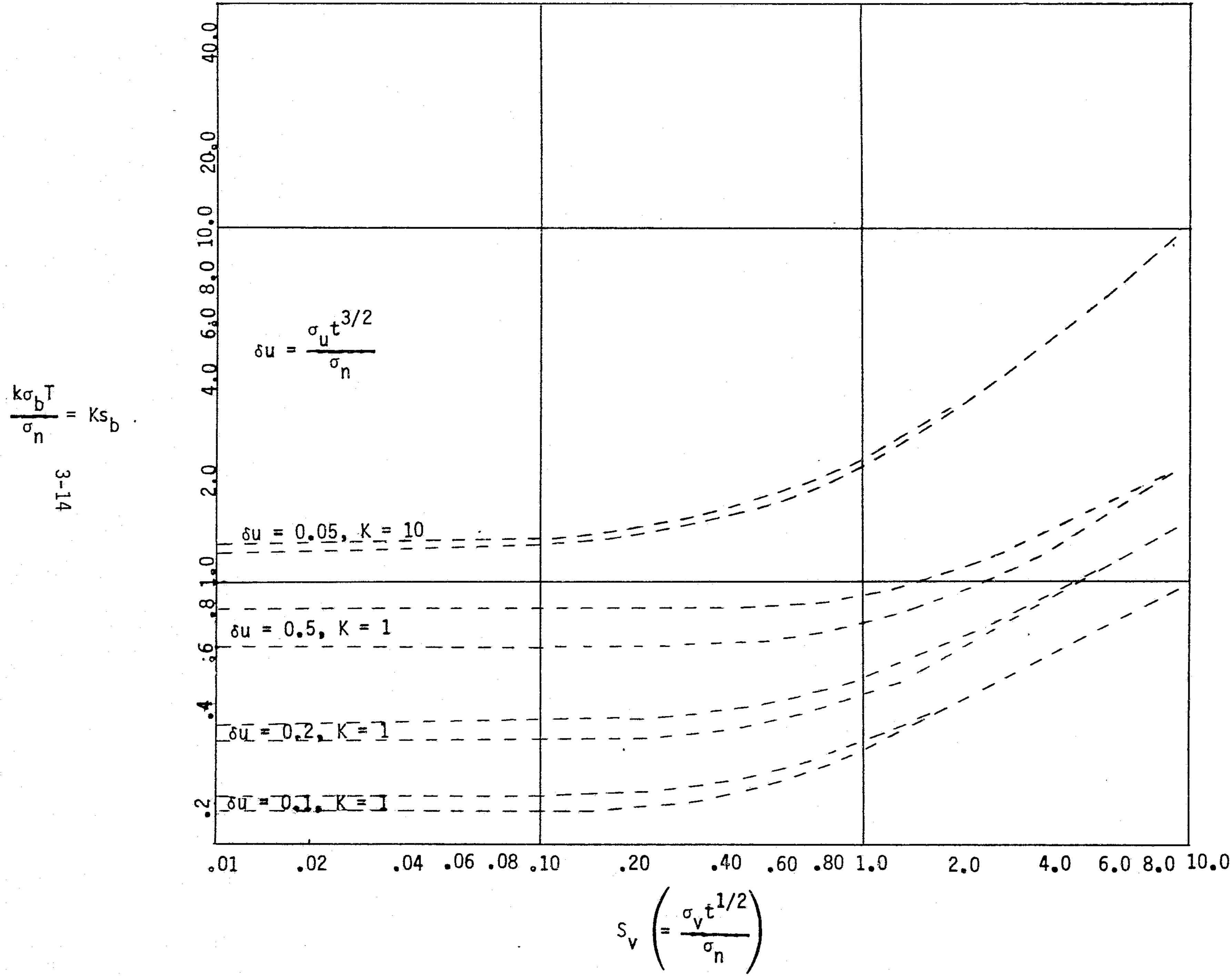


Figure 3-4. Performance Estimate Tradeoff Curves

where:

$P_j \;=\; E[xx^T]$ at time t_j just after an update

$S_j \;=\; E[xx^T]$ at time t_j just before an update

It is necessary to derive the state transition matrix, Φ, the state noise covariance matrix, Q, the measurement matrix, M, and the measurement noise covariance matrix, R, based upon the system model.

The spacecraft is assumed to be three-axis stabilized to an earth pointing, local vertical reference frame rotating at orbit rate, ω_o. The attitude of the spacecraft [b-frame] relative to the reference [r-frame] is given by:

$$\begin{bmatrix} \bar{x}_b \\ \bar{y}_b \\ \bar{z}_b \end{bmatrix} = \begin{bmatrix} 1 & \theta_3 & -\theta_2 \\ -\theta_3 & 1 & \theta_1 \\ \theta_2 & -\theta_1 & 1 \end{bmatrix} \begin{bmatrix} \bar{x}_r \\ \bar{y}_r \\ \bar{z}_r \end{bmatrix}$$

PADS is assumed configured with gyro measured rates (attitude) in three orthogonal axes [b-frame]. The single-gimbal star tracker is mounted to provide mechanical scan in a plane normal to the orbit plane (shown previously in Figure 3-1), with tracker axes [j-frame] related to the body axes [b-frame] as:

$$\begin{bmatrix} x_j \\ y_j \\ z_j \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_b \\ y_b \\ z_b \end{bmatrix}$$

where

x_j = axis of gimbal rotational freedom

y_j = nominal sensor boresight at zero gimbal rotation

z_j = form right-handed orthogonal frame with x_j, y_j

From Section 3.2.2, each gyro is assumed to satisfy a mathematical model given by

$$\omega_m^i = \omega^i + w^i + v^i \qquad i = 1,2,3$$

where v^i is a white noise component; w^i is the random walk gyro drift rate; and

$$\begin{aligned} \omega^1 &= \dot{\theta}_1 - \omega_o \theta_3 \\ \omega^2 &= \dot{\theta}_2 - \omega_o \\ \omega^3 &= \dot{\theta}_3 + \omega_o \theta_1 \end{aligned}$$

Therefore:

$$\begin{aligned} \omega_m^1 &= \dot{\theta}_1 - \omega_o \theta_3 + w^1 + v^1 \\ \omega_m^2 &= \dot{\theta}_2 - \omega_o + w^2 + v^2 \\ \omega_m^3 &= \dot{\theta}_3 + \omega_o \theta_1 + w^3 + v^3 \end{aligned}$$

For estimates:

$$\begin{aligned} \omega_m^1 &= \dot{\hat{\theta}}_1 - \omega_o \hat{\theta}_3 + \hat{w}^1 \\ \omega_m^2 &= \dot{\hat{\theta}}_2 - \omega_o \\ \omega_m^3 &= \dot{\hat{\theta}}_3 + \omega_o \hat{\theta}_1 + \hat{w}^3 \end{aligned}$$

Setting $\delta\theta_i = \theta_i - \hat{\theta}_i$ and $\delta w^i = w^i - \hat{w}^i$

$$\delta\dot{\theta}_1 = \omega_o\, \delta\theta_3 - \delta w^1 - v^1$$

$$\delta\dot{\theta}_2 = -\delta w^2 - v^2$$

$$\delta\dot{\theta}_3 = -\omega_o\, \delta\theta_1 - \delta w^3 - v^2$$

Also, as w^i is a random walk

$$\dot{w}^i = u^i, \qquad \dot{\hat{w}}^i = 0$$

and therefore:

$$\delta\dot{w}^i = \dot{w}^i - \dot{\hat{w}}^i = u^i$$

where u^i is random white noise.

Since pitch and roll/yaw decouple kinematically, separate solutions can be obtained for pitch and roll/yaw. For pitch

$$\begin{bmatrix} \delta\theta_2 \\ \delta w^2 \end{bmatrix}_{j+1} = \begin{bmatrix} 1 & -\tau_{j+1} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \delta\theta_2 \\ \delta w^2 \end{bmatrix}_j + \int_{t_j}^{t_{j+1}} \begin{bmatrix} -v^2-(\tau-s)u^2 \\ u^2 \end{bmatrix} ds$$

For roll/yaw:

$$\begin{bmatrix} \delta\dot{\theta}_1 \\ \delta\dot{w}^1 \\ \delta\dot{\theta}_3 \\ \delta\dot{w}^3 \end{bmatrix} = \begin{bmatrix} 0 & -1 & \omega_o & 0 \\ 0 & 0 & 0 & 0 \\ -\omega_o & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \delta\theta \\ \delta w^1 \\ \delta\theta_3 \\ \delta w^3 \end{bmatrix} + \begin{bmatrix} -v^1 \\ u^1 \\ -v^3 \\ u^3 \end{bmatrix}$$

$$\delta w^i(t) = \delta w^i(t_j) + \int_{t_j}^{t} u^i\, ds; \qquad i = 1,3;\ t_j \leq t \leq t_{j+1}$$

Then for $t_j \leq t \leq t_{j+1}$

$$\delta\dot{\theta}_1 = -\delta w_j^1 - \int_{t_j}^{t} u^1 \, ds + \omega_o \, \delta\theta_3 - v^1$$

$$\delta\dot{\theta}_3 = -\omega_o \, \delta\theta_1 - \delta w_j^3 - \int_{t_j}^{t} u^3 \, ds - v^3$$

for which the honogeneous solution is developed as:

$$\begin{bmatrix} \delta\theta_1(t_{j+1}) \\ \delta w^1(t_{j+1}) \\ \delta\theta_3(t_{j+1}) \\ \delta w^3(t_{j+1}) \end{bmatrix} = \begin{bmatrix} \cos \omega_o \tau_{j+1} & -\tau_{j+1} & \sin \omega_o \tau_{j+1} & 0 \\ 0 & 1 & 0 & 0 \\ -\sin \omega_o \tau_{j+1} & 0 & \cos \omega_o \tau_{j+1} & -\tau_{j+1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \delta\theta_1(t_j) \\ \delta w^1(t_j) \\ \delta\theta_3(t_j) \\ \delta w^3(t_j) \end{bmatrix}$$

The (full) state transition matrix is summarized:

$$\Phi = \begin{bmatrix} C & -\tau_{j+1} & 0 & 0 & S & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -\tau_{j+1} & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ -S & 0 & 0 & 0 & C & -\tau_{j+1} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

where: $C = \cos \omega_o \tau_{j+1}$, $S = \sin \omega_o \tau_{j+1}$

The state noise covariance matrix for roll/yaw is developed from the particular solutions:

$$x(t_{j+1}) = B(t)\int_0^t \begin{bmatrix} \cos\omega_o s & s\cos\omega_o s & -\sin\omega_o s & -s\sin\omega_o s \\ 0 & 1 & 0 & 0 \\ \sin\omega_o s & s\sin\omega_o s & \cos\omega_o s & s\sin\omega_o s \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -v^1 \\ u^1 \\ -v^3 \\ \cdot \end{bmatrix} ds = \begin{bmatrix} q^1 \\ q^2 \\ q^3 \\ q^4 \end{bmatrix}$$

where B(t) is the matrix for the homogeneous solution.

After very considerable algebraic manipulation,

$$E\left[q_1^2\right] = E\left[q_3^2\right] = \sigma_u^2\left[\frac{4}{3}\tau^3 - \frac{2\tau}{\omega_o^2}(1-\cos\omega_o\tau)\right] + \sigma_v^2\,\tau$$

$$E\left[q_2^2\right] = E\left[q_4^2\right] = \sigma_u^2\,\tau$$

$$E\left[q_1q_2\right] = E\left[q_2q_1\right] = E\left[q_3q_4\right] = E\left[q_4q_3\right] = \sigma_u^2\left[\frac{1-\cos\omega_o\tau}{\omega_o^2} - \tau^2\right]$$

$$E\left[q_1q_4\right] = E\left[q_4q_1\right] = E\left[q_2q_3\right] = E\left[q_3q_2\right] = \frac{\sigma_u^2}{\omega_o}\left(\tau - \frac{\sin\omega_o\tau}{\omega_o}\right)$$

$$E\left[q_1q_3\right] = E\left[q_3q_1\right] = E\left[q_2q_4\right] = E\left[q_4q_2\right] = 0$$

Thus, the full state noise covariance matrix, Q, has the form:

$$
Q = \begin{bmatrix}
\sigma_u^2\left[\frac{4}{3}\tau^3 - \frac{2\tau}{\omega_o^2}(1-\cos\omega_o\tau)\right]+\sigma_v^2\tau & \sigma_u^2\left[\frac{1-\cos\omega_o\tau}{\omega_o^2} - \tau^2\right] & 0 & 0 & 0 & \frac{\sigma_u^2}{\omega_o}\left(\tau - \frac{\sin\omega_o\tau}{\omega_o}\right) \\
\sigma_u^2\left[\frac{1-\cos\omega_o\tau}{\omega_o^2} - \tau^2\right] & \sigma_u^2\tau & 0 & 0 & \frac{\sigma_u^2}{\omega_o}\left(\tau - \frac{\sin\omega_o\tau}{\omega_o}\right) & 0 \\
0 & 0 & \sigma_v^2\tau & 0 & 0 & 0 \\
0 & 0 & 0 & \sigma_u^2\tau & 0 & 0 \\
0 & \frac{\sigma_u^2}{\omega_o}\left(\tau - \frac{\sin\omega_o\tau}{\omega_o}\right) & 0 & 0 & \sigma_u^2\left[\frac{4}{3}\tau^3 - \frac{2\tau}{\omega_o}\left(1-\cos\omega_o\tau\right)\right]+\sigma_v^2\tau & \sigma_u^2\left[\frac{1-\cos\omega_o\tau}{\omega_o^2} - \tau^2\right] \\
\frac{\sigma_u^2}{\omega_o}\left(\tau - \frac{\sin\omega_o\tau}{\omega_o}\right) & 0 & 0 & 0 & \sigma_u^2\left[\frac{1-\cos\omega_o\tau}{\omega_o^2} - \tau^2\right] & \sigma_u^2\tau
\end{bmatrix}
$$

To establish the measurement equation, results previously developed for the two-gimbal tracker are used directly with the constraint that the inner gimbal is "locked". Recalling the measurement equation as:

$$y = \begin{bmatrix} y_I \\ y_o \end{bmatrix} = \begin{bmatrix} -u_1 \\ \dfrac{u_3}{\sqrt{1-u_1^2}} \end{bmatrix} + \begin{bmatrix} 0 & -\sqrt{1-u_1^2} \\ -\dfrac{u_2}{1-u_1^2} & 0 \end{bmatrix} \begin{bmatrix} \alpha_1^M - n_1 \\ \alpha_2^M - n_2 \end{bmatrix}$$

where

y_I	is the sine of the inner gimbal
y_o	is the sine of the outer gimbal
α_1^M, α_2^M	are the star sensor outputs
n_1, n_2	is the sensor noise

and

$$u_i = \overline{u}_s \cdot \begin{Bmatrix} \overline{x}_j \\ \overline{y}_j \\ \overline{z}_j \end{Bmatrix} \qquad i = 1,2,3$$

where $\overline{u}_s$ is the star unit vector defined in the reference axes as:

$$\overline{u}_s = a_1 \overline{x}_r + a_2 \overline{y}_r + a_3 \overline{z}_r$$

The key constraint is applied by assuring that a_1 is <u>first order</u>, $a_3 < 0$ and $\Sigma a_i^2 = 1$

Therefore:

$$u_1 = a_1 + a_2\,\theta_3 - a_3\,\theta_2 \text{ (1st order)}$$

$$u_2 = -a_1\,\theta_2 + a_2\,\theta_1 - a_3$$

$$u_3 = -a_1\,\theta_3 + a_2 + a_3\,\theta_1$$

Substitution for u_i in the prior equation yields:

$$y = \begin{bmatrix} y_I \\ y_o \end{bmatrix} = \begin{bmatrix} 0 & a_3 & -a_2 \\ a_3 & 0 & 0 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix} + \begin{bmatrix} -a_1 - \alpha_2^M + n_2 \\ a_2 + a_3\,\alpha_1^M - a_3\,n_1 \end{bmatrix}$$

$$\hat{y} = \begin{bmatrix} 0 & a_3 & -a_2 \\ a_3 & 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{\theta}_1 \\ \hat{\theta}_2 \\ \hat{\theta}_3 \end{bmatrix} + \begin{bmatrix} -a_1 - \alpha_2^M \\ a_2 + a_3\,\alpha_1^M \end{bmatrix}$$

and

$$\delta y = y - \hat{y} = \begin{bmatrix} 0 & a_3 & -a_2 \\ a_3 & 0 & 0 \end{bmatrix} \delta\theta + \begin{bmatrix} n_2 \\ -a_3\,n_1 \end{bmatrix}$$

Therefore, the measurement matrix, M, is given as

$$M_{j+1} = \begin{bmatrix} 0 & 0 & -\sqrt{1-a_2^2} & 0 & -a_2 & 0 \\ -\sqrt{1-a_2^2} & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The measurement noise covariance matrix, R, is given as:

$$R_{j+1} = \begin{bmatrix} 1 & 0 \\ 0 & a_3^2 \end{bmatrix}_{j+1} \sigma_n^2$$

3.3.2 Performance Evaluation

The covariance analysis digital computer program was used to evaluate performance potential and tradeoffs. Those elements evaluated for tradeoffs include star sensor noise and gyro random drift characteristics. The computer program provides a time history of the error covariance. Summary data, used as the performance measure, includes the average estimation error covariance and final value of gyro bias estimation error covariance.

The program was run with several sets of initial conditions to evaluate both the convergence properties and steady-state performance. Convergence to steady-state accuracies from initial attitude uncertainty of 0.1 degree (1σ) and gyro bias uncertainty of 0.1 degree/hour (1σ) was achieved within four (4) star sightings. Cases for evaluation of steady-state performance had initial conditions of 10 arc-seconds (1σ) in attitude uncertainty and 0.05 degree/hour (1σ) in gyro bias uncertainty. Small initial transients were noted in the attitude covariance.

Table 3-5 summarizes the observed covariance analysis results as summarized by the computer program performance measures. The gyro parameters are consistent with a range of values based upon observed test data (see Figure 3-3). The star tracker errors are consistent with those developed in the error analysis of Table 3-3. Evaluation of performance goal of 0.001 degree (= 3.6 arc-seconds) is achievable in the high altitude (geosynchronous)

Table 3-5. Table of Performance Results[1]

Tracker Noise σ_n ($\widehat{\text{sec}}$)	Gyro Random Drift $\sigma_v \frac{(\widehat{\text{sec}}/\text{sec})}{(\text{rad/sec})^{1/2}}$	Gyro Random Drift $\sigma_u \frac{(\widehat{\text{sec}}/\text{sec}^2)}{(\text{rad/sec})^{1/2}}$	Attitude Estimate σ_{θ_i} ($\widehat{\text{sec}}$)	Gyro Bias Estimate σ_{b_i} (deg/hr)
2	.115	3.33×10^{-5}	4.6/6.1/6.2	.0024/.0026/.0025
2	.05	3.33×10^{-5}	3.2/4.2/4.1	.002/.0022/.0021
2	.05	1.6×10^{-5}	2.6/3.1/3.1	.0011/.0012/.0012
3	.115	3.33×10^{-5}	5.0/6.4/6.5	.0024/.0026/.0025
3	.05	3.2×10^{-5}	3.5/4.4/4.3	.0016/.002/.0018
3	.05	1.6×10^{-5}	3.0/3.5/3.4	.001/.0012/.0011
3	.015	3.2×10^{-5}	3.1/3.8/3.7	.0014/.0018/.0016
3	.015	1.6×10^{-5}	2.5/2.7/2.7	.0009/.001/.0009

[1] All cases - geosynchronous orbit, real stars brighter than $m_V = +3.5$, star tracker boresight South, gimbal freedom ±45 degrees

application using the current PADS single-gimbal star tracker and available state-of-the art strapdown gyros. Certain general conclusions may also be developed, namely:

- Small star tracker noise variations are observed to have little effect on overall performance
- Gyro drift characteristics have the largest effect on performance
- Changes in the gyro drift term, σ_v, have a moderate effect on attitude and bias estimation
- Changes in gyro drift term, σ_u, have (almost) a direct effect on the bias estimation

A typical time history of the attitude estimation performance is shown in Figure 3-5. The time-history plotted is the square-root of the trace of the attitude error covariance matrix. Selected case history output data is included in Appendix B.

A8

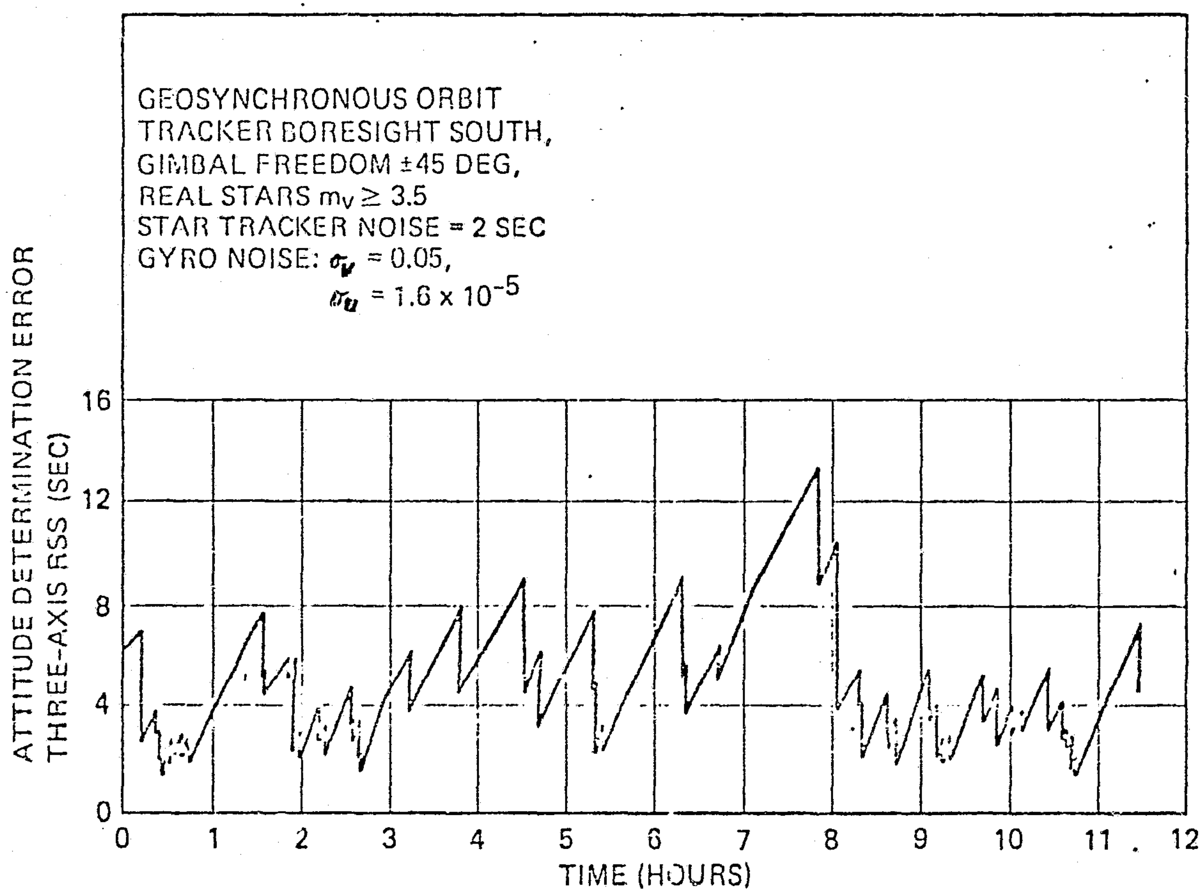

GEOSYNCHRONOUS ORBIT
TRACKER BORESIGHT SOUTH,
GIMBAL FREEDOM ±45 DEG,
REAL STARS $m_v \geq 3.5$
STAR TRACKER NOISE = 2 SEC
GYRO NOISE: σ_v = 0.05,
$\sigma_u = 1.6 \times 10^{-5}$
ATTITUDE DETERMINATION ERROR
THREE-AXIS RSS (SEC)
0
4
8
12
16
0 1 2 3 4 5 6 7 8 9 10 11 12
TIME (HOURS)

Figure 3-5

4.0 REFERENCES

(1) 13900-6014-RU-00, PADS System Design and Analysis (Two-Axis Gimbal Star Tracker), 1 July 1973.

(2) 13900-6015-RU-00, PADS Star Tracker Test, 1 July 1973.

(3) Farrenkopf, R. L., Generalized Results and Other Considerations in Attitude Determination Involving Gyros, TRW IOC 74.7530.3-11, 21 January 1974.

APPENDIX A

COMPUTER PROGRAM FOR STAR AVAILABILITY

A.1 Program LØØK1

Program LØØK1 is a FORTRAN program to determine and order stars observed by a star sensor mounted on an earth orbiting spacecraft. The program works from stars in a general catalog (input file TAPE1) which includes RA, DEC, magnitude, and catalog number. Each star is tested in turn for the position in orbit that observation may be made including tests for sun interference, earth interference, and constraints of orbit, time of year, and sensor/spacecraft geometry. If observation is determined, the star is ordered in a working catalog on the basis of orbit angle from ascending node at the position of observation. The star LOS is defined by orbit angle and angle measured from zenith at the indicated orbit angle. The input file used for current investigations is given in A.2 and the output file of ordered stars used for covariance analysis given in A.3.

```
      PROGRAM LOOK1(INPUT,OUTPUT,TAPE1=INPUT,TAPE2,TAPE3)
C     TAPE3 CONTAINS MASTER STAR CATALOG
      DIMENSION NNS(400),NUS(400),GAM(400),ALPH(400)
      REAL INCL,MV,MVLIM
      REWIND 3
      DATA OMEG,INCL,S/0.,0.,0./
      DATA MVLIM,SUNLIM,BETA,GAMLIM/3.5,45.,-45.,45./
      NAMELIST/DATA/OMEG,INCL,S,MVLIM,SUNLIM,BETA,GAMLIM
      READ(1,DATA)
      DISPLAY *OMEG,INCL,S= *,OMEG,INCL,S
      DISPLAY *MVLIM,SUNLIM,BETA,GAMLIM= *,MVLIM,SUNLIM,BETA,GAMLIM
      DEGRAD=3.1415927/180.
      RADDEG=1./DEGRAD
      SUNLIM=DEGRAD*SUNLIM
      GAMLIM=DEGRAD*GAMLIM
      OMEG=DEGRAD*OMEG
      INCL=DEGRAD*INCL
      S=DEGRAD*S
      ACCEPT(3) NS
      L=1
      DO 500 I=1,NS
      ACCEPT(3) NSL,NSC,RA,DEC,MV
C     TEST ON STAR MAGNITUDE
      IF(MV.GT.MVLIM)GO TO 500
C     FORM STAR DIRECTION COSINES
      RA=DEGRAD*RA
      DEC=DEGRAD*DEC
      A1=COS(DEC)*COS(RA)
      A2=COS(DEC)*SIN(RA)
      A3=SIN(DEC)
C     TEST SUN INTERFERENCE
      S1=COS(S)
      S2=SIN(S)*COS(.408)
      S3=SIN(S)*SIN(.408)
      DOTSUN=A1*S1+A2*S2+A3*S3
      IF(DOTSUN.GT.COS(SUNLIM))GO TO 500
      NNS(L)=I
      FLAG=0.
C     DETERMINE REF PLANE-ORBIT PLANE INTERSECTION
      B1=SIN(INCL)*SIN(OMEG)
      B2=-SIN(INCL)*COS(OMEG)
      B3=COS(INCL)
```

```
      V1=A2*B3-A3*B2
      V2=A3*B1-A1*B3
      V3=A1*B2-A2*B1
      W1=B2*V3-B3*V2
      W2=B3*V1-B1*V3
      W3=B1*V2-B2*V1
      W=SQRT(W1*W1+W2*W2+W3*W3)
      W1=W1/W
      W2=W2/W
      W3=W3/W
C     COMPUTE ANGLE FROM ZENITH FOR STAR LOS
      GAMMA=ACOS(W1*A1+W2*A2+W3*A3)
      IF((A1*B1+A2*B2+A3*B3).GT.0.)GO TO 100
      GO TO 200
  100 GAMMA=-GAMMA
  200 IF(ABS(GAMMA-DEGRAD*BETA).GT.GAMLIM)GO TO 500
      GAM(L)=RADDEG*GAMMA
C     COMPUTE ORBIT ANGLE FOR REF PLANE INTERSECT
      AN1=COS(OMEG)
      AN2=SIN(OMEG)
      SALPHAO=B3*(-AN2*W1+AN1*W2)+(B1*AN2-B2*AN1)*W3
      CALPHAO=AN1*W1+AN2*W2
      ALPHAO=ATAN2(SALPHAC,CALPHAO)
      ALPH(L)=RADDEG*ALPHAO
      IF(ALPH(L).LT.0.)ALPH(L)=ALPH(L)+360.
C     SORT ON BASIS OF ORBIT ANGLE
  250 NUS(L)=L
      ITEMP2=NUS(1)
      DO 300 J=1,L
      M=NUS(J)
      IF(ALPH(L).LT.ALPH(M))GO TO 400
      ITEMP2=NUS(J+1)
  300 CONTINUE
  400 NUS(J)=NUS(L)
      DO 450 K=J,L
      ITEMP1=ITEMP2
      ITEMP2=NUS(K+1)
      NUS(K+1)=ITEMP1
  450 CONTINUE
C     COMPLETE SORT
C     TEST FOR ALPHA+180
      IF(FLAG.GT.1.)GO TO 480
```

```
      FLAG=2.
      IF(ABS(180.-GAM(L)-BETA).GT.GAMLIM*RADDEG)GO TO 480
      L=L+1
      NNS(L)=I
      GAM(L)=180.-GAM(L-1)
      ALPH(L)=ALPH(L-1)+180.
      IF(ALPH(L).GT.360.) ALPH(L)=ALPH(L)-360.
      GO TO 250
  480 CONTINUE
      L=L+1
  500 CONTINUE
C     END OF SORT ITERATION LOOP
C     PRINT ORDERED CATALOG
      L=L-1
      DISPLAY (2) L
      DO 700 I=1,L
      J=NUS(I)
      DISPLAY (2) I,NNS(J),ALPH(J),GAM(J)
  700 CONTINUE
      END
```

A.2 <u>Yale Catalog of Bright Stars to 4th Magnitude</u>

Data includes (from L to R):

- Working catalog order (ordered by magnitude)
- Yale Catlog Number
- Right Ascension
- Declination
- Magnitude (S-20)

396

TAPE3 = STACAT

1	2491	100.91355	-16.67130	-1.4600
2	4210	160.93650	-59.51870	-1.0000
3	2326	95.79915	-52.66630	-.5754
4	7001	278.94600	38.74930	.0400
5	1713	78.22530	-8.23967	.0487
6	472	24.10905	-57.42000	.2599
7	5267	210.35700	-60.20230	.3440
8	1708	78.54330	45.96600	.6580
9	2943	114.38010	5.31833	.6880
10	5056	200.84850	-10.97430	.7019
11	5340	213.52800	19.35900	.7217
12	7564	297.31200	32.83170	.7525
13	5459	219.32250	-60.69170	.8356
14	4853	191.43600	-59.51300	.9698
15	7557	297.28050	8.77600	.9772
16	3982	151.63950	12.13100	1.2420
17	4730	186.17700	-62.91300	1.2480
18	8728	343.94400	-29.79800	1.2490
19	2618	104.32395	-28.92130	1.2540
20	2061	88.33125	7.39433	1.3320
21	7924	310.06800	45.14770	1.3490
22	6527	262.82400	-37.07730	1.3500
23	1790	80.82720	6.32167	1.3820
24	1903	83.61930	-1.22267	1.4900
25	1457	68.49180	16.43200	1.5000
26	1948	84.76245	-1.96700	1.5060
27	1791	81.03390	28.57170	1.5090
28	3207	122.12130	-47.24800	1.5250
29	8425	331.52250	-47.13100	1.5890
30	2890	113.10735	31.95700	1.6110
31	5191	206.54850	49.48670	1.6380
32	6134	246.83250	-26.35970	1.6380
33	3685	138.20655	-69.57500	1.7010
34	7790	305.73750	-56.84100	1.7080
35	2294	95.30100	-17.93300	1.7100
36	4905	193.13400	56.13700	1.7390
37	2990	115.80930	28.10170	1.7300
38	6879	275.47800	-34.40030	1.8090
39	4731	186.18150	-62.91300	1.8320
40	2004	86.53785	-9.67800	1.8420
41	7121	283.29000	-26.33970	1.8780

42	15	1.65666	28.89630	1.9130
43	2421	98.93760	16.42830	1.9300
44	2088	89.26005	44.94430	1.9310
45	3165	120.59685	-39.90370	1.9550
46	1852	82.56930	-.32267	1.9660
47	3485	130.94400	-54.59200	1.9910
48	5958	239.52000	26.01300	2.0000
49	2891	113.10735	31.95700	2.0210
50	5132	204.43200	-53.29100	2.0420
51	5469	219.91800	-47.25270	2.0540
52	936	46.49190	40.81970	2.0870
53	5440	218.33550	-42.00270	2.1280
54	4819	189.91050	-48.77970	2.1390
55	6580	265.03350	-39.01630	2.1520
56	1017	50.47560	49.73100	2.1920
57	5953	239.58000	-22.52030	2.2020
58	5793	233.31150	26.83000	2.2090
59	6556	263.34000	12.58930	2.2250
60	6553	263.71800	-42.97730	2.2280
61	4534	176.83350	14.75930	2.2290
62	4763	187.32000	-56.92400	2.2440
63	3734	140.26560	-54.86930	2.2680
64	5231	208.35300	-47.13000	2.2820
65	5054	200.64000	55.10900	2.2900
66	5460	219.32250	-60.69170	2.3170
67	2827	110.68515	-29.23200	2.3260
68	4295	164.94900	56.56470	2.3390
69	2693	106.75425	-26.34330	2.3550
70	264	13.66217	60.53530	2.4040
71	5571	224.07600	-42.99730	2.4120
72	3699	139.04685	-59.12500	2.4120
73	4301	165.40950	61.93130	2.4320
74	8781	345.76800	15.01870	2.4370
75	4554	178.00800	53.88700	2.4400
76	6508	262.11300	-37.27170	2.4540
77	4662	183.51600	-17.34630	2.4820
78	1899	83.44185	-5.93933	2.4870
79	4798	188.78850	-68.94630	2.4880
80	6378	257.10900	-15.67700	2.4900
81	5685	228.79200	-9.25867	2.4920
82	1956	84.60510	-34.10030	2.5010
83	424	31.96755	89.08570	2.5080

84	3307	125.45490	-59.39230	2.5130
85	4199	160.43400	-64.20770	2.5140
86	5776	233.22150	-41.05330	2.5240
87	4621	181.64700	-50.52970	2.5340
88	2095	89.34975	37.20000	2.5450
89	5984	240.86400	-19.70930	2.5450
90	4656	183.33600	-58.56300	2.5500
91	21	1.83834	58.96300	2.5610
92	6217	251.26500	-68.97100	2.5640
93	39	2.87058	14.99630	2.5720
94	6175	248.82000	-10.49870	2.5800
95	8162	319.44300	62.44170	2.6260
96	4057	154.52700	20.02000	2.6350
97	337	16.95735	35.43530	2.6460
98	3748	141.47790	-8.51933	2.6470
99	617	31.31280	23.29130	2.6550
100	5944	239.19750	-26.02030	2.6700
101	188	10.46942	-18.17030	2.6740
102	4357	168.07350	20.70370	2.6770
103	7194	285.11250	-29.91770	2.6800
104	5288	211.17000	-36.21330	2.6840
105	1220	58.89165	39.90370	2.6930
106	8636	340.15950	-47.05900	2.7190
107	5563	222.79650	74.29170	2.7200
108	2845	111.32700	8.35133	2.7330
109	7796	305.25000	40.14230	2.7410
110	6510	262.30500	-49.85500	2.7420
111	4915	193.60950	38.49800	2.7610
112	603	30.44955	42.16900	2.7610
113	1165	56.36505	24.00900	2.7640
114	553	28.19220	20.63570	2.7770
115	1865	82.80795	-17.85600	2.7970
116	2282	94.74915	-30.04970	2.7980
117	5028	199.66800	-36.53530	2.8010
118	403	20.89740	60.05770	2.8070
119	3634	136.68690	-43.29730	2.8190
120	4844	191.04900	-67.92970	2.8300
121	1122	55.12425	47.67570	2.8380
122	7528	295.97700	45.04830	2.8490
123	1910	83.90385	21.12730	2.8490
124	5576	224.23500	-41.96400	2.8500
125	6705	268.95300	51.48900	2.8610

126	8353	327.96900	-37.52530	2.8710
127	5671	228.93450	-68.55870	2.8900
128	5531	222.25050	-15.90830	2.8950
129	8238	322.05300	70.40270	2.8970
130	168	9.64608	56.34630	2.8980
131	6247	252.39150	-37.99330	2.9060
132	4757	187.02300	-16.32970	2.9080
133	1666	76.54455	-5.12867	2.9270
134	6241	251.99100	-34.23770	2.9350
135	5695	229.78350	-40.52530	2.9520
136	2653	105.40275	-23.78230	2.9550
137	3445	129.87645	-46.53100	2.9570
138	1203	57.99930	31.78130	2.9570
139	1641	76.03275	41.18800	2.9720
140	7235	285.96300	13.81570	2.9900
141	5505	220.87500	27.22500	2.9930
142	6084	244.78350	-25.50400	3.0260
143	897	44.24085	-40.43600	3.0270
144	99	6.15150	-42.48700	3.0360
145	8322	326.28900	-16.28630	3.0460
146	6453	259.97850	-24.96600	3.0460
147	4825	189.98550	-1.26300	3.0490
148	2451	99.18105	-43.15500	3.0520
149	6396	257.17500	65.75630	3.0520
150	8308	325.62750	9.72467	3.0530
151	6165	248.44050	-28.14870	3.0610
152	4467	173.55300	-62.82970	3.0670
153	7039	280.88550	-27.03400	3.0730
154	7949	311.20950	33.84200	3.0870
155	5735	230.24550	71.95230	3.1000
156	5897	238.03800	-63.32570	3.1130
157	591	29.42385	-61.73100	3.1250
158	622	31.87755	34.82470	3.1270
159	911	45.12600	3.96400	3.1330
160	1788	80.69295	-2.41733	3.1400
161	5948	239.46900	-38.30370	3.1420
162	5190	206.86500	-41.51330	3.1420
163	5708	230.08950	-44.57530	3.1500
164	5235	208.26600	18.57000	3.1530
165	1465	68.31585	-55.11800	3.1530
166	1702	77.85090	-16.23970	3.1620
167	8775	345.53400	27.89630	3.1680

168	7710	302.38650	-.91867	3.1770
169	6462	260.63400	-56.34930	3.1780
170	1879	83.31585	9.91067	3.1920
171	3185	121.52475	-24.20370	3.1960
172	7178	284.41650	32.63800	3.1970
173	5435	217.67850	38.46400	3.2110
174	542	27.98805	63.51330	3.2160
175	7264	286.93650	-21.07330	3.2190
176	6410	258.40800	24.87300	3.2200
177	3659	137.51775	-58.82500	3.2200
178	4037	153.23550	-69.86330	3.2250
179	5193	206.89200	-42.31330	3.2360
180	3117	118.97910	-52.89270	3.2500
181	4786	188.14950	-23.21300	3.2600
182	98	5.99126	-77.44270	3.2750
183	1239	59.69640	12.38700	3.2810
184	8634	339.93900	10.65770	3.2830
185	4216	161.32650	-49.25200	3.2830
186	1577	73.69605	33.09900	3.2910
187	4359	168.11550	15.62030	3.3000
188	6897	276.11550	-45.98370	3.3020
189	5506	220.87500	27.22500	3.3030
190	5854	235.65150	6.52433	3.3080
191	3569	134.22195	48.16930	3.3120
192	6252	252.50850	-37.96000	3.3140
193	6212	250.00050	31.66230	3.3150
194	2773	108.98715	-37.03770	3.3160
195	5354	214.30650	-45.90800	3.3300
196	7236	286.11150	-4.93433	3.3330
197	8709	343.21200	-15.99800	3.3400
198	6132	245.88150	61.57930	3.3460
199	6056	243.13800	-3.59833	3.3490
200	7525	296.15850	10.53170	3.3510
201	6859	274.70550	-29.83370	3.3600
202	6148	247.18800	21.55700	3.3850
203	153	8.76851	53.71300	3.3880
204	4660	183.43800	57.22030	3.3900
205	4140	157.70250	-61.50770	3.3930
206	5463	219.93750	-64.81930	3.3940
207	3890	146.56245	-64.90800	3.3990
208	3447	129.83130	-52.79770	3.4000
209	6615	266.30100	-40.10530	3.4070

210	6536	262.41600	52.33930	3.4100
211	1829	81.69840	-20.77830	3.4160
212	7106	282.20400	33.32700	3.4200
213	674	33.82185	-51.67530	3.4210
214	1347	64.15335	-33.88500	3.4210
215	6603	265.44750	4.58367	3.4270
216	1605	74.88105	43.78230	3.4300
217	3940	148.91775	-54.41900	3.4340
218	915	45.58380	53.36970	3.4390
219	4932	195.12150	11.14800	3.4550
220	2550	101.96220	-61.89930	3.4590
221	3975	151.36950	16.93100	3.4590
222	1735	78.98775	-6.88400	3.4610
223	2286	95.22735	22.53370	3.4680
224	5107	203.24100	-.42433	3.4680
225	8232	322.44450	-5.73067	3.4730
225	5812	234.14400	-29.67000	3.4730
227	6913	276.46800	-25.45030	3,4790
228	1931	84.26115	-2.61700	3.4800
229	4033	153.76200	43.08670	3.4810
230	3468	130.55445	-33.07550	3.4820
231	6461	260.61750	-55.49930	3.4910
232	5881	236.96100	-3.31467	3.4970
233	6500	262.00650	-60.65500	3.5030
234	1552	72.35085	5.54333	3.5030
235	8502	334.04250	-60.42000	3.5090
236	1567	73.11915	2.39333	3.5100
237	838	41.99580	27.12500	3.5230
238	8762	345.08850	42.13530	3.5240
239	3873	145.98075	23.92530	3.5280
240	1178	56.78595	23.94800	3.5350
241	8650	340.35150	30.04100	3.5430
242	8414	331.00950	-.48100	3.5550
243	804	40.38435	3.09167	3.5590
244	8675	341.62500	-51.49800	3.5600
245	6743	270.99600	-50.10000	3.5640
246	3775	142.54445	51.83630	3.5690
247	1142	55.71240	24.00900	3.5720
248	1543	72.00060	6.89333	3.5720
249	5248	209.04900	-41.93570	3.5740
250	2553	102.27225	-50.57700	3.5780
251	1412	66.68070	15.79300	3.5820

252	7913	310.47300	-66.32470	3.5840
253	2356	96.79185	-7.01067	3.5850
254	1231	59.11170	-13.61300	3.5860
255	5291	210.86850	64.53100	3.5870
256	3594	135.32475	47.28600	3.6000
257	6588	264.62250	46.03370	3.6020
258	8450	332.12100	6.03000	3.6090
259	6746	270.90450	-30.43330	3.6100
260	2948	114.35565	-26.72070	3.6230
261	5249	209.14500	-44.63570	3.6260
262	5020	199.26750	-23.00200	3.6290
263	7776	304.77600	-14.89100	3.6340
264	2473	100.46055	25.16730	3.6380
265	5928	238.69950	-29.11470	3.6460
266	7377	290.94300	3.04867	3.6490
267	1998	86.35215	-14.84470	3.6490
268	1038	51.33120	9.61433	3.6550
269	4630	182.09550	-22.42970	3.6630
270	4335	166.93950	44.67030	3.6630
271	4069	155.07300	41.67000	3.6660
272	2749	108.35580	-26.71000	3.6680
273	4743	186.55200	-50.04630	3.6780
274	6380	257.42650	-43.18800	3.6780
275	5646	227.39250	-48.60300	3.6790
276	4773	187.60800	-71.94630	3.6850
277	1463	68.65410	-3.41800	3.6860
278	2763	109.03620	16.59570	3.6880
279	2540	102.63630	34.00630	3.6890
280	2538	102.14100	-32.47700	3.6900
281	5605	225.69900	-46.91970	3.6930
282	4133	157.75650	9.47567	3.6980
283	7310	288.13650	67.60430	3.7000
284	4390	169.86600	-54.31300	3.7050
285	7906	309.51750	15.79770	3.7070
286	4787	188.00850	69.97030	3.7110
287	4031	153.70200	23.58670	3.7110
288	6406	258.27450	14.42300	3.7120
289	3571	133.56975	-60.51970	3.7220
290	6092	244.67850	46.39600	3.7260
291	7869	308.79450	-47.40230	3.7300
292	5867	236.15400	15.52430	3.7300
293	6285	253.95450	-55.93230	3.7390

294	5511	221.13300	2.04167	3.7400
295	7417	292.33650	27.89300	3.7440
296	3663	137.62395	-62.17500	3.7500
297	3547	133.40085	6.08033	3.7500
298	2484	100.84755	12.93400	3.7520
299	6832	273.83250	-36.77800	3.7530
300	3803	142.54635	-56.88600	3.7530
301	4520	175.99950	-66.52970	3.7650
302	2040	87.44130	-35.77800	3.7670
303	3705	139.74540	34.54170	3.7750
304	8518	334.97400	-1.55333	3.7770
305	7950	311.46000	-9.62467	3.7800
306	8585	337.47150	50.10770	3.7800
307	6561	263.91300	-15.37730	3.7810
308	4232	161.98500	-16.00770	3.7820
309	4638	182.46750	-52.17970	3.7850
310	1149	55.94835	24.25900	3.7860
311	6629	266.54850	2.72800	3.7910
312	5471	219.96300	-37.65270	3.8020
313	6779	271.55250	28.76100	3.8090
314	6418	258.46650	36.83970	3.8140
315	3665	138.14970	2.45833	3.8170
316	6771	271.43550	9.56100	3.8190
317	4898	193.15050	-56.99630	3.8220
318	2777	109.52205	22.04570	3.8240
319	779	39.43455	.18600	3.8240
320	7337	290.04750	-44.52900	3.8240
321	1654	76.00680	-22.41200	3.8300
322	8115	317.87250	30.09170	3.8300
323	5477	219.88050	13.86400	3.8300
324	338	16.73880	-55.43130	3.8330
325	545	27.91305	19.11900	3.8380
326	5849	235.33050	26.40770	3.8400
327	6149	247.30050	2.05700	3.8400
328	595	30.06915	2.60233	3.8400
329	4679	184.14750	-63.81300	3.8420
330	7348	290.38500	-40.67900	3.8420
331	6299	254.02500	9.43433	3.8470
332	544	27.78630	29.41900	3.8490
333	5626	226.63650	-45.15300	3.8520
334	5892	237.28050	4.58533	3.8550
335	1520	70.95000	-3.31233	3.8560

336	8974	354.48450	77.42970	3.8570
337	6630	266.88450	-37.03870	3.8580
338	1208	57.12165	-74.35200	3.8590
339	6075	244.12950	-4.61500	3.8600
340	5453	218.89800	-49.26930	3.8650
341	165	9.37859	30.67970	3.8730
342	6869	274.88550	-2.89467	3.8750
343	3055	117.04905	-46.28170	3.8780
344	3314	125.99160	-3.80333	3.8790
345	3482	131.24535	6.54133	3.8800
346	1131	55.54650	32.17570	3.8800
347	3690	139.17990	36.95830	3.8800
348	2878	112.03920	-43.23200	3.8850
349	5883	237.19800	-33.51470	3.8870
350	4023	153.32700	-41.96330	3.8900
351	3786	142.34070	-40.31930	3.8990
352	322	16.14120	-46.89800	3.9000
353	3487	131.21655	-45.92530	3.9000
354	4689	184.54050	-.47967	3.9000
355	3129	119.31465	-49.14270	3.9020
356	5287	211.11150	-26.51900	3.9020
357	5603	225.51900	-25.14730	3.9080
358	5993	241.20300	-20.57600	3.9080
359	5747	231.60450	29.21900	3.9090
360	6324	254.74950	30.96770	3.9100
361	4802	188.96100	-48.34630	3.9100
362	7852	307.89750	11.18670	3.9110
363	219	11.76075	57.63530	3.9130
364	6623	266.28300	27.75030	3.9140
365	5744	231.04350	59.08570	3.9180
366	3852	144.83415	10.05300	3.9190
367	7590	299.16450	-72.99070	3.9190
368	2216	93.20385	22.51130	3.9190
369	1251	60.33555	5.90367	3.9200
370	8597	338.40150	-.29233	3.9240
371	7420	92.21050	51.65970	3.9260
372	3323	126.86115	60.83000	3.9430
373	1336	63.49515	-62.55170	3.9460
374	1949	84.76245	-1.96700	3.9520
375	4826	189.98550	-1.26300	3.9530
376	3757	142.21320	63.21400	3.9540
377	8278	324.55050	-16.81970	3.9560

378	1756	79.50060	-13.21730	3.9600
379	8028	313.97850	41.03630	3.9600
380	1922	83.33055	-62.50600	3.9680
381	580	30.13155	72.25230	3.9700
382	6698	269.28600	-9.77767	3.9700
383	2657	105.55350	-15.58230	3.9710
384	7234	286.20300	-27.71770	3.9780
385	6095	245.10750	19.22930	3.9810
386	8465	332.41800	58.03000	3.9840
387	4386	169.84500	6.22033	3.9860
388	269	13.71575	38.31300	3.9880
389	1273	61.54905	47.62600	3.9890
390	6714	269.73300	2.93333	3.9900
391	921	45.75045	38.70300	3.9950
392	6927	275.68350	72.71630	3.9950
393	1983	85.76250	-22.46130	3.9960
394	2085	88.71330	-14.17230	3.9960
395	5367	214.62000	-37.74130	3.9980
396	5987	241.08750	-36.70930	4.0000

A.3 Ordered Working Star Catalog

Shown is the ordered working catalog derived from Program LØØK1 for single-gimbal tracker, boresight South, ±45° FOV gimbal, $m_V = +3.5$. Data output includes:

- Local catalog order (ordered by orbit angle measured from ascending node)
- Working catalog number (see A.2)
- Orbit angle of observation
- Angle from zenith

Note: Output is provided on file named TAPE2

TAPE2 This run has: Boresight δ (β=90) δ_{un} =45 (±45° gated line)

104			
1	87	1.647005318	1.294703E+02
2	90	3.336005318	1.21437E+02
3	182	5.99126	7.74427E+01
4	17	6.177005318	1.17087E+02
5	39	6.181505318	1.17087E+02
6	62	7.320005318	1.23076E+02
7	79	8.788505318	1.110537E+02
8	54	9.910505318	1.312203E+02
9	120	1.104900532E+01	1.120703E+02
10	14	1.143600532E+01	1.20487E+02
11	6	2.410905E+01	5.742E+01
12	50	2.443200532E+01	1.26709E+02
13	64	2.835300532E+01	1.3287E+02
14	157	2.942385E+01	6.1731E+01
15	7	3.035700532E+01	1.197977E+02
16	213	3.382185E+01	5.16753E+01
17	195	3.430650532E+01	1.34092E+02
18	13	3.932250532E+01	1.193083E+02
19	66	3.932250532E+01	1.193083E+02
20	51	3.991800532E+01	1.327473E+02
21	206	3.993750532E+01	1.151807E+02
22	127	4.893450532E+01	1.114413E+02
23	156	5.803800532E+01	1.166743E+02
24	165	6.831585E+01	5.5118E+01
25	92	7.126500532E+01	1.11029E+02
26	231	8.061750532E+01	1.245007E+02
27	169	8.063400532E+01	1.236507E+02
28	110	8.230500532E+01	1.30145E+02
29	3	9.579915E+01	5.26663E+01
30	188	9.611550532E+01	1.340163E+02
31	220	1.019622E+02	6.18993E+01
32	180	1.189791E+02	5.28927E+01
33	28	1.221213E+02	4.7248E+01
34	84	1.254549E+02	5.93923E+01
35	34	1.257375053E+02	1.23159E+02
36	208	1.298313E+02	5.27977E+01
37	137	1.2987645E+02	4.6531E+01
38	47	1.30944E+02	5.4592E+01
39	177	1.3751775E+02	5.8825E+01
40	33	1.3820655E+02	6.9575E+01
41	72	1.3904685E+02	5.9125E+01

42	63	1.402656E+02	5.48693E+01
43	207	1.4656245E+02	6.4908E+01
44	217	1.4891775E+02	5.4419E+01
45	29	1.515225053E+02	1.32869E+02
46	178	1.532355E+02	6.98633E+01
47	205	1.577025E+02	6.15077E+01
48	106	1.601595053E+02	1.32941E+02
49	85	1.60434E+02	6.42077E+01
50	2	1.609365E+02	5.95187E+01
51	185	1.613265E+02	4.9252E+01
52	152	1.73553E+02	6.28297E+01
53	87	1.816470053E+02	5.05297E+01
54	90	1.833360053E+02	5.8563E+01
55	182	1.8599126E+02	1.025573E+02
56	17	1.861770053E+02	6.2913E+01
57	39	1.861815053E+02	6.2913E+01
58	62	1.873200053E+02	5.6924E+01
59	79	1.887885053E+02	6.89463E+01
60	54	1.899105053E+02	4.87797E+01
61	120	1.910490053E+02	6.79297E+01
62	14	1.914360053E+02	5.9513E+01
63	6	2.0410905E+02	1.2258E+02
64	50	2.044320053E+02	5.3291E+01
65	64	2.083530053E+02	4.713E+01
66	157	2.0942385E+02	1.18269E+02
67	7	2.103570053E+02	6.02023E+01
68	213	2.1382185E+02	1.283247E+02
69	195	2.143065053E+02	4.5908E+01
70	13	2.193225053E+02	6.06917E+01
71	66	2.193225053E+02	6.06917E+01
72	51	2.199180053E+02	4.72527E+01
73	206	2.199375053E+02	6.48193E+01
74	127	2.289345053E+02	6.85587E+01
75	156	2.380380053E+02	6.33257E+01
76	165	2.4831585E+02	1.24882E+02
77	92	2.512650053E+02	6.8971E+01
78	231	2.606175053E+02	5.54993E+01
79	169	2.606340053E+02	5.63493E+01
80	110	2.623050053E+02	4.9855E+01
81	3	2.7579915E+02	1.273337E+02
82	188	2.761155053E+02	4.59837E+01
83	220	2.819622E+02	1.181007E+02

84	180	2.989791E+02	1.271073E+02
85	28	3.021213E+02	1.32752E+02
86	84	3.054549E+02	1.206077E+02
87	34	3.057375053E+02	5.6841E+01
88	208	3.098313E+02	1.272023E+02
89	137	3.0987645E+02	1.33469E+02
90	47	3.10944E+02	1.25408E+02
91	177	3.1751775E+02	1.21175F+02
92	33	3.1820655E+02	1.10425E+02
93	72	3.1904685E+02	1.20875E+02
94	63	3.202656E+02	1.251307E+02
95	207	3.2656245E+02	1.15092E+02
96	217	3.2891775E+02	1.25581E+02
97	29	3.315225053E+02	4.7131F+01
98	178	3.332355E+02	1.101367E+02
99	205	3.377025E+02	1.184923E+02
100	106	3.401595053F+02	4.7059E+01
101	85	3.40434E+02	1.157923E+02
102	2	3.409365E+02	1.204813E+02
103	185	3.413265E+02	1.30748E+02
104	152	3.53553E+02	1.171703E+02

APPENDIX B

COMPUTER PROGRAM FOR SINGLE-GIMBAL PADS COVARIANCE ANALYSIS

B.1 Program PADSCØ

A FORTRAN digital computer program, Program PADSCØ, was developed to implement the covariance analysis algorithms derived in Section 3.3. The program operated using star data from file TAPE2 and input data defining orbit and filter characteristics. A source program listing is provided, followed by a summary of output data in B.2.

```
      PROGRAM PADSCO(INPUT,OUTPUT,TAPE1,TAPE2,TAPE5=INPUT)
C     TAPE2 CONTAINS STAR DATA
      DIMENSION P(6,6),S(6,6),SS(3,2)
      DIMENSION ALPH(400),GAM(400),N(400),NNS(400),A(3)
      COMMON W0
      REWIND 2
      NAMELIST/PARAM/T1,T2,T3,W,SN,SV,SU,H,TF,TG
      DATA T1,T2,T3/10.,10.,10./
      DATA W/.05/
      DATA SN,SV,SU/3.,.115,.333E-4/
      DATA H,TF,TG/19300.,86400.,21600./
      READ(5,PARAM)
      WRITE(1,2) T1,T2,T3,W,SN,SV,SU,H
      PRINT 2,T1,T2,T3,W,SN,SV,SU,H
    2 FORMAT(X,11HT1,T2,T3 = ,3(F6.1,2X)/X,4HW = ,E9.2/X,11HSN,SV,SU = ,
     13(E9.2,2X)/X,4HH = ,F7.1/)
      WRITE(1,3)
    3 FORMAT(4X,1HT,7X,2HS1,6X,2HS2,6X,2HS3,6X,2HPS,6X,2HRS,
     16X,2HT1,6X,2HT2,6X,2HT3,6X,2HPT,6X,2HRT/)
      ACCEPT (2) NSTR
      ACCEPT (2) (N(I),NNS(I),ALPH(I),GAM(I),I=1,NSTR)
      DEGRAD=3.1415927/180.
      IR=0
C     INITIALIZE TIME
      T=T9=0.
C     INITIALIZE PERFORMANCE MEASURE
      DO 11 I=1,3
   11 SS(I,1)=SS(I,2)=0.
C     INITIALIZE ERROR COVARIANCE MATRIX
      DO 10 I=1,6
      DO 10 J=1,6
   10 P(I,J)=0.
      P(1,1)=T1**2
      P(3,3)=T2**2
      P(5,5)=T3**2
      P(2,2)=P(4,4)=P(6,6)=W**2
      W0=SQRT(1.875E5/3./(3440.+H)**3)
   20 RT=SQRT(T1**2+T2**2+T3**2)
      RS=SQRT(S1**2+S2**2+S3**2)
      PS=SQRT(S1**2+S2**2)
      PT=SQRT(T1**2+T2**2)
      PRINT 8,T,RS,RT
```

```
    8 FORMAT(X,F7.1,2(2X,F6.1))
      WRITE(1,4) T,S1,S2,S3,PS,RS,T1,T2,T3,PT,RT
    4 FORMAT(X,F7.1,10(2X,F6.1))
C     COMPUTE TIME TO NEXT UPDATE,DT
      IR=IR+1
      IF(IR.GT.1) GO TO 21
      DT=ALPH(1)*DEGRAD/W0
      GO TO 24
   21 IF(IR.LE.NSTP) GO TC 22
      IR=1
      DT=(360.-ALPH(NSTR)+ALPH(1))*DEGRAD/W0
      GO TO 24
   22 DT=(ALPH(IR)-ALPH(IR-1))*DEGRAD/W0
C     COMPUTE STAR COORDINATES
   24 A(1)=0.
      A(2)=SIN(GAM(IR))
      A(3)=-COS(GAM(IR))
C     TEST/COMPUTE CUM PERFORMANCE MEASURE
      IF(T.LT.TG) GO TO 30
      DO 40 I=1,3
      J=2*I-1
      K=J+1
      A=P(K,K)
      B=SV**2-2.*P(J,K)
      C=P(J,J)
      SS(I,2)=SS(I,2)+A*DT**3/3.+B*DT**2/2.+C*DT
      RR=(4.*A*C-B**2)/8./A**1.5
      CC=-B/4./A*SQRT(C)-RR*ALOG(ABS(2.*SQRT(A*C)+B))
      X=A*DT**2+B*DT+C
      R1=(2.*A*DT+B)/4./A*SQRT(X)+RR*ALOG(ABS(2.*SQRT(A*X)
     1+2.*A*DT+B))
      SS(I,1)=SS(I,1)+R1+CC
   40 CONTINUE
      T9=T9+DT
C     INCREMENT TIME TO NEXT STAR
   30 T=T+DT
C     TEST FOR END OF RUN,TF
      IF(T.GT.TF) GO TO 100
      CALL FILTER(P,S,DT,SN,SV,SU,A)
      S1=SQRT(S(1,1))
      S2=SQRT(S(3,3))
      S3=SQRT(S(5,5))
```

```
      T1=SQRT(P(1,1))
      T2=SQRT(P(3,3))
      T3=SQRT(P(5,5))
      GO TO 20
C     COMPUTE EOR PERF. MEASURE:MEAN,SIGMA
  100 CONTINUE
      DO 50 I=1,3
      SS(I,1)=SS(I,1)/T9
      SS(I,2)=SQRT(SS(I,2)/T9-SS(I,1)**2)
   50 CONTINUE
      PRINT 5
    5 FORMAT(5X,4HMEAN,4X,5HSIGMA/)
      DO 60 I=1,3
   60 PRINT 6,SS(I,1),SS(I,2)
C     ESTIMATED GYRO BIASES
      PP1=SQRT(P(2,2))
      PP2=SQRT(P(4,4))
      PP3=SQRT(P(6,6))
      PRINT 7,PP1,PP2,PP3
    7 FORMAT(X,14HGYRO BIASES = ,3(E10.3,2X))
    6 FORMAT(2(2X,F6.2))
      END
C
C
C
      SUBROUTINE FILTER(P,S,DT,SN,SV,SU,Y)
      DIMENSION P(6,6),S(6,6),Q(6,6),R(2,2),RM(2,6),PHI(6,6),A(6,6),
     1B(6,2),C(2,2),D(2,2),G(6,2),H(6,6),Y(3)
      COMMON W0
C     ZERO MATRIX ELEMENTS
      DO 10 J=1,6
      RM(1,J)=RM(2,J)=0.
      DO 10 I=1,6
   10 Q(I,J)=PHI(I,J)=0.
C     MEASUREMENT NOISE COVARIANCE MATRIX
      R(1,2)=R(2,1)=0.
      R(1,1)=(SN/2.)**2
      R(2,2)=(SN*Y(3))**2
C     STATE TRANSITION MATRIX,PHI
      DO 20 I=1,6
   20 PHI(I,I)=1.
      S8=SIN(W0*DT)
```

```
      C8=COS(W0*DT)
      PHI(1,1)=PHI(5,5)=C8
      PHI(1,5)=S8
      PHI(5,1)=-S8
      PHI(1,2)=PHI(3,4)=PHI(5,6)=-DT
C     STATE NOISE COVARIANCE MATRIX,Q
      T4=4.*DT**3/3.-2.*DT*(1.-C8)/W0**2
      Q(3,3)=DT*SV**2+SU**2*DT**3/3.
      Q(1,1)=Q(5,5)=DT*SV**2+T4*SU**2
      Q(1,2)=Q(2,1)=Q(5,6)=Q(6,5)=((1.-C8)/W0**2-DT**2)*SU**2
      Q(1,6)=Q(6,1)=Q(2,5)=Q(5,2)=SU**2*(DT-S8/W0)/W0
      Q(2,2)=Q(4,4)=Q(6,6)=DT*SU**2
      Q(3,4)=Q(4,3)=-(SU*DT)**2/2.
C     MEASUREMENT MATRIX,RM
      RM(1,3)=RM(2,1)=Y(3)
      RM(1,5)=-Y(2)
C     PROPAGATE ERROR COVARIANCE,S=PHI*P*PHIT+Q
      DO 30 I=1,6
      DO 30 J=1,6
      A(I,J)=0.
      DO 30 K=1,6
   30 A(I,J)=A(I,J)+P(I,K)*PHI(J,K)
      DO 40 I=1,6
      DO 40 J=1,6
      S(I,J)=Q(I,J)
      DO 40 K=1,6
   40 S(I,J)=S(I,J)+PHI(I,K)*A(K,J)
C     COMPUTE OPTIMAL GAIN,G
      DO 50 I=1,6
      DO 50 J=1,2
      B(I,J)=0.
      DO 50 K=1,6
   50 B(I,J)=B(I,J)+S(I,K)*RM(J,K)
      DO 60 I=1,2
      DO 60 J=1,2
      C(I,J)=R(I,J)
      DO 60 K=1,6
   60 C(I,J)=C(I,J)+RM(I,K)*B(K,J)
      DEL=C(1,1)*C(2,2)-C(1,2)*C(2,1)
      D(1,1)=C(2,2)/DEL
      D(1,2)=-C(1,2)/DEL
      D(2,1)=-C(2,1)/DEL
```

```
      D(2,2)=C(1,1)/DEL
      DO 70 I=1,6
      DO 70 J=1,2
      G(I,J)=0.
      DO 70 K=1,2
   70 G(I,J)=G(I,J)+B(I,K)*D(K,J)
C     UPDATE ERROR COVARIANCE,P
      DO 80 I=1,6
      DO 81 J=1,6
   81 H(I,J)=-G(I,1)*RM(1,J)-G(I,2)*RM(2,J)
   80 H(I,I)=H(I,I)+1.
      DO 90 I=1,6
      DO 90 J=1,6
      A(I,J)=0.
      DO 90 K=1,6
   90 A(I,J)=A(I,J)+H(I.K)*S(K,J)
C     ASSURE POS. DEF. P
      DO 100 I=1,6
      DO 100 J=1,6
  100 P(I,J)=(A(I,J)+A(J,I))*.5
      RETURN
      END
```

B.2 Summary of Test Cases

Star Data Used From Appendix A

Geosynchronous Orbit

Tracker - Nominal Boresight S, Gimbal Freedom ±45°

m_V Brighter than +3.5, Real Stars

Initial Att. Covariance T1/T2/T3 (arc-sec)	Initial Gyro Bias Covariance W (deg/hr)	Sensor Noise SN (arc-sec)	Gyro Noise SV	Gyro Noise SU
10/10/10	.05	3	.115 (2 sec in 5 minutes)	$3.33\text{x}10^{-5}$ (.002 deg/hr/hr)
10/10/10	.05	3	.05	$3.2\text{x}10^{-5}$
	.05	3	.05	$1.6\text{x}10^{-5}$
	.05	3	.015	$3.2\text{x}10^{-5}$
	.05	3	.015	$1.6\text{x}10^{-5}$
360/360/360	.05	3	.05	$1.6\text{x}10^{-5}$
10/10/10	0.1	3	.05	$1.6\text{c}10^{-5}$
360/360/360	0.1	3	.05	$1.6\text{x}10^{-5}$

T1,T2,T3 = 10.0 10.0 10.0
W = 5.00E-02
SN,SV,SU = 3.00E+00 1.15E-01 3.33E-05
H = 19300.0

T	S1	S2	S3	PS	RS	T1	T2	T3	PT	RT
0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	10.0	14.1	17.3
394.3	22.2	22.2	22.2	31.4	38.5	3.0	13.8	17.5	14.1	22.5
798.6	11.0	26.7	33.1	28.9	43.9	2.9	9.0	4.9	9.5	10.7
1434.3	8.9	22.1	14.7	23.8	27.9	2.8	22.0	11.4	22.2	24.9
1478.8	3.1	22.9	11.9	23.1	26.0	2.1	2.0	1.4	2.9	3.3
1479.8	2.2	2.0	1.5	2.9	3.3	1.7	1.7	1.4	2.5	2.8
1752.4	3.1	3.2	2.9	4.5	5.3	2.2	2.2	2.8	3.1	4.1
2104.0	3.8	3.8	4.6	5.4	7.0	2.3	3.8	2.5	4.5	5.1
2372.6	3.5	5.0	3.7	6.1	7.1	2.3	2.1	2.1	3.1	3.8
2645.1	3.3	3.2	3.2	4.6	5.6	2.2	3.1	2.2	3.8	4.4
2737.8	2.6	3.4	2.6	4.3	5.0	2.0	2.1	1.3	2.9	3.2
5771.7	11.9	12.1	11.4	17.0	20.4	2.9	9.4	7.9	9.8	12.6
5849.0	3.1	9.6	8.1	10.1	12.9	2.2	7.7	5.3	8.0	9.5
6787.7	4.9	10.1	7.5	11.2	13.5	2.6	9.5	7.1	9.8	12.1
7044.1	3.3	10.1	7.7	10.6	13.2	2.2	2.7	1.6	3.5	3.9
7267.4	3.0	3.4	2.5	4.5	5.1	2.1	1.6	2.2	2.6	3.4
8096.9	4.5	4.2	4.6	6.2	7.7	2.5	4.2	1.6	4.9	5.1
8213.0	2.9	4.5	2.1	5.3	5.7	2.1	2.7	1.5	3.4	3.7
9413.8	5.4	5.9	5.1	8.0	9.5	2.6	1.5	5.1	3.0	6.0
9413.8	2.6	1.5	5.1	3.0	6.0	2.0	1.1	5.1	2.3	5.6
9556.3	2.5	1.8	5.5	3.1	6.3	1.9	1.6	2.3	2.5	3.4
9561.0	1.9	1.6	2.3	2.5	3.4	1.6	1.3	1.3	2.1	2.4
11714.9	7.5	7.4	7.4	10.5	12.9	2.8	7.4	1.6	7.9	8.0
13894.3	8.2	13.0	7.5	15.4	17.1	2.8	3.8	7.4	4.7	8.8
16354.8	9.0	9.5	13.7	13.1	18.9	2.8	8.3	1.9	8.8	9.0
17060.8	4.7	10.1	4.0	11.1	11.8	2.5	5.3	2.8	5.9	6.5
19299.8	8.3	10.6	8.5	13.4	15.9	2.8	8.0	3.6	8.5	9.2
19303.7	2.8	8.0	3.6	8.5	9.2	2.1	2.5	1.2	3.2	3.4
19703.8	3.3	3.6	2.7	4.9	5.6	2.2	3.5	1.5	4.2	4.4
22934.3	10.6	11.6	10.2	15.7	18.7	2.9	7.1	7.8	7.7	10.9
23010.0	3.1	7.3	7.9	7.9	11.2	2.2	4.9	3.6	5.3	6.5
24409.7	5.9	8.1	6.9	10.0	12.2	2.7	7.4	5.6	7.9	9.6
28483.5	13.1	17.7	15.3	22.0	26.8	2.9	8.8	15.2	9.2	17.8
29235.8	4.9	10.1	17.3	11.3	20.6	2.5	1.5	6.6	2.9	7.3
30033.8	4.7	4.1	8.3	6.3	10.4	2.5	2.3	6.7	3.4	7.5

30101.5	2.7	2.5	6.8	3.7	7.8	2.0	1.4	2.4	2.5	3.5
31081.5	4.8	4.5	5.1	6.6	8.3	2.6	2.9	3.9	3.8	5.5
31092.3	2.6	2.9	4.0	3.9	5.6	2.0	2.8	3.9	3.4	5.2
31347.9	2.8	3.5	4.6	4.5	6.4	2.1	2.2	1.5	3.0	3.4
32921.7	6.4	6.5	6.1	9.1	10.9	2.7	4.8	4.2	5.5	6.9
33086.6	3.2	5.2	4.6	6.1	7.7	2.2	1.5	2.2	2.7	3.4
33287.7	2.8	2.3	2.8	3.7	4.6	2.1	1.6	2.3	2.6	3.5
33579.5	3.0	2.7	3.2	4.0	5.2	2.1	2.6	1.4	3.3	3.6
35087.0	6.2	6.6	5.8	9.0	10.7	2.7	5.6	3.3	6.2	7.0
35650.8	4.2	7.0	4.8	8.2	9.5	2.5	3.5	2.2	4.2	4.8
36274.4	4.2	5.0	4.1	6.6	7.7	2.4	4.4	3.4	5.0	6.0
36684.5	3.6	5.4	4.4	6.5	7.9	2.3	4.4	4.4	4.9	6.6
37753.9	5.3	6.9	7.0	8.7	11.2	2.6	5.1	1.8	5.7	6.0
38342.1	4.2	6.5	3.7	7.8	8.6	2.4	3.9	2.5	4.6	5.2
38407.8	2.7	4.1	2.7	4.8	5.5	2.0	3.7	1.6	4.2	4.5
38528.1	2.4	4.0	2.1	4.7	5.2	1.9	1.4	1.8	2.3	2.9
38621.5	2.2	1.8	2.1	2.9	3.6	1.8	1.7	1.5	2.5	2.9
41548.5	9.5	9.5	9.4	13.5	16.4	2.9	1.5	9.4	3.2	9.9
43486.2	7.7	6.9	14.4	10.4	17.8	2.8	3.6	12.6	4.5	13.4
43890.5	3.9	4.6	13.6	6.0	14.9	2.4	2.7	1.9	3.6	4.1
44526.2	4.2	4.5	3.9	6.1	7.2	2.4	4.3	2.4	4.9	5.5
44570.7	2.6	4.4	2.6	5.1	5.7	2.0	1.4	1.8	2.4	3.0
44571.7	2.0	1.4	1.8	2.4	3.0	1.6	1.0	1.8	1.9	2.6
44844.3	2.6	2.3	2.7	3.5	4.4	2.0	1.5	2.5	2.5	3.5
45195.9	3.1	2.8	3.6	4.2	5.5	2.2	1.4	3.4	2.6	4.2
45464.5	3.0	2.4	4.1	3.9	5.7	2.1	2.4	1.4	3.2	3.5
45737.0	3.0	3.3	2.5	4.5	5.1	2.1	3.1	1.6	3.7	4.1
45829.7	2.5	3.3	2.0	4.1	4.6	1.9	1.5	1.9	2.4	3.1
48863.6	9.9	9.6	10.0	13.8	17.0	2.9	1.6	9.9	3.3	10.5
48940.9	3.1	1.9	10.1	3.6	10.8	2.2	1.2	8.2	2.5	8.5
49879.6	4.8	4.3	10.4	6.4	12.2	2.5	1.4	10.3	2.9	10.7
50135.9	3.3	2.4	10.9	4.1	11.7	2.2	2.4	2.0	3.3	3.9
50359.3	2.9	3.1	2.8	4.3	5.1	2.1	1.6	2.2	2.7	3.4
51188.8	4.5	4.2	4.5	6.2	7.7	2.5	2.3	3.8	3.4	5.1
51304.8	2.9	2.7	4.2	3.9	5.7	2.1	2.5	1.9	3.2	3.7
52505.7	5.4	5.7	5.3	7.9	9.5	2.6	4.4	3.0	5.1	5.9
52505.7	2.6	4.4	3.0	5.1	5.9	2.0	4.4	2.9	4.8	5.6
52648.2	2.5	4.7	3.3	5.3	6.3	1.9	1.6	2.3	2.5	3.4
52652.9	1.9	1.6	2.4	2.5	3.4	1.6	1.3	1.3	2.1	2.4
54806.8	7.5	7.3	7.4	10.5	12.8	2.8	4.1	6.3	4.9	8.0
56986.2	8.3	9.3	11.7	12.5	17.1	2.8	4.0	7.3	4.9	8.8
59446.7	9.0	10.1	13.2	13.5	18.9	2.8	6.0	6.1	6.6	9.0

60152.7	4.7	7.7	7.7	9.0	11.8	2.5	1.8	5.7	3.1	6.5
62391.7	8.3	7.8	11.1	11.4	15.9	2.8	7.5	4.6	8.0	9.2
62395.6	2.8	7.5	4.6	8.0	9.2	2.1	1.7	2.2	2.7	3.4
62795.7	3.3	3.1	3.4	4.5	5.6	2.2	1.9	3.3	2.9	4.4
66026.2	10.6	10.4	11.4	14.8	18.7	2.9	10.4	1.8	10.8	10.9
66101.9	3.1	10.6	2.1	11.0	11.2	2.2	5.7	2.1	6.1	6.5
67501.6	5.9	8.9	5.9	10.7	12.2	2.7	8.8	3.0	9.2	9.7
71575.4	13.1	19.4	13.2	23.4	26.9	2.9	17.6	2.6	17.9	18.1
72327.7	4.8	19.7	4.7	20.3	20.8	2.5	5.2	4.4	5.8	7.3
73125.7	4.7	6.7	6.4	8.2	10.4	2.5	6.5	2.9	6.9	7.5
73193.4	2.7	6.6	3.1	7.1	7.8	2.0	1.8	2.2	2.7	3.5
74173.4	4.8	4.7	4.9	6.7	8.3	2.6	4.7	1.4	5.3	5.5
74184.2	2.6	4.7	1.5	5.4	5.6	2.0	4.7	1.1	5.1	5.2
74439.8	2.8	5.4	2.2	6.1	6.5	2.1	1.6	2.2	2.6	3.4
76013.6	6.4	6.1	6.5	8.8	10.9	2.7	6.0	2.0	6.6	6.9
76178.5	3.2	6.5	2.6	7.2	7.7	2.2	1.8	2.0	2.8	3.4
76379.6	2.8	2.5	2.7	3.8	4.6	2.1	2.5	1.3	3.2	3.5
76671.4	3.0	3.4	2.5	4.5	5.2	2.1	1.8	2.3	2.8	3.6
78178.9	6.2	6.1	6.3	8.7	10.7	2.7	5.8	3.0	6.4	7.0
78742.7	4.2	7.2	4.4	8.3	9.4	2.5	1.5	3.8	2.9	4.8
79366.3	4.2	3.6	5.4	5.5	7.7	2.4	1.4	5.3	2.8	6.0
79776.4	3.7	2.9	6.3	4.7	7.9	2.3	1.6	6.0	2.8	6.6
80845.8	5.3	4.8	8.6	7.2	11.2	2.6	4.0	3.6	4.8	6.0
81434.0	4.2	5.5	5.0	7.0	8.6	2.4	1.5	4.3	2.9	5.2
81499.7	2.7	1.8	4.5	3.2	5.5	2.0	1.6	3.7	2.6	4.5
81620.0	2.4	2.1	4.0	3.2	5.2	1.9	1.6	1.6	2.5	2.9
81713.4	2.2	2.0	1.9	3.0	3.6	1.8	1.9	1.3	2.6	2.9
84640.4	9.5	9.6	9.3	13.5	16.4	2.9	7.6	5.7	8.1	9.9

T1,T2,T3 = 10.0 10.0 10.0

W = 5.00E-02

SN,SV,SU = 3.00E+00 5.00E-02 3.20E-05

H = 19300.0

T	S1	S2	S3	PS	RS	T1	T2	T3	PT	RT
0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	10.0	14.1	17.3
394.3	22.1	22.1	22.1	31.3	38.3	3.0	13.7	17.4	14.0	22.4
798.6	10.7	26.5	32.9	28.6	43.6	2.9	8.7	4.7	9.2	10.3
1434.3	8.1	21.5	14.1	22.9	26.9	2.8	21.4	11.1	21.6	24.3
1478.8	3.0	22.3	11.6	22.5	25.3	2.1	1.9	1.4	2.9	3.2
1479.8	2.1	1.9	1.4	2.9	3.2	1.7	1.6	1.3	2.4	2.7
1752.4	2.5	2.4	2.1	3.5	4.0	1.9	1.8	2.0	2.6	3.3

2104.0	2.9	2.8	3.1	4.0	5.0	2.1	2.7	2.1	3.4	4.0
2372.6	2.7	3.5	2.7	4.4	5.2	2.0	1.6	1.5	2.6	3.0
2645.1	2.6	2.1	2.1	3.3	3.9	2.0	2.0	1.6	2.8	3.2
2737.8	2.1	2.2	1.7	3.1	3.5	1.7	1.7	1.1	2.4	2.6
5771.7	8.0	7.7	6.9	11.1	13.1	2.8	5.9	5.0	6.5	8.2
5849.0	2.9	6.0	5.1	6.7	8.4	2.1	5.5	3.9	5.9	7.0
6787.7	3.4	7.2	5.3	7.9	9.5	2.2	6.9	5.2	7.2	8.9
7044.1	2.6	7.3	5.6	7.8	9.6	2.0	2.1	1.3	2.9	3.2
7267.4	2.3	2.4	1.6	3.3	3.7	1.8	1.4	1.6	2.3	2.8
8096.9	3.0	2.6	2.8	4.0	4.9	2.1	2.6	1.4	3.4	3.7
8213.0	2.3	2.8	1.6	3.6	4.0	1.8	2.0	1.2	2.7	3.0
9413.8	3.7	3.9	3.1	5.4	6.2	2.3	1.4	3.1	2.7	4.1
9413.8	2.3	1.4	3.1	2.7	4.1	1.8	1.1	3.1	2.1	3.8
9556.3	2.0	1.3	3.3	2.4	4.1	1.7	1.1	1.9	2.0	2.8
9561.0	1.7	1.2	1.9	2.0	2.8	1.5	1.0	1.2	1.8	2.2
11714.9	4.9	4.6	4.7	6.8	8.2	2.6	4.6	1.5	5.3	5.5
13894.3	6.0	9.0	4.9	10.9	11.9	2.7	2.8	4.9	3.8	6.2
16354.8	6.6	6.5	9.8	9.3	13.5	2.7	5.5	1.6	6.2	6.4
17060.8	3.7	6.9	2.6	7.8	8.2	2.3	3.8	1.9	4.4	4.8
19299.8	5.9	7.5	5.7	9.6	11.1	2.7	5.5	2.6	6.1	6.6
19303.7	2.7	5.5	2.6	6.1	6.6	2.0	2.4	1.1	3.1	3.3
19703.8	2.5	2.9	1.7	3.8	4.2	1.9	2.8	1.2	3.4	3.6
22934.3	7.6	8.6	6.9	11.4	13.3	2.8	5.0	5.4	5.7	7.8
23010.0	2.9	5.1	5.5	5.9	8.0	2.1	4.0	3.1	4.5	5.5
24409.7	4.1	6.2	5.2	7.4	9.0	2.4	5.9	4.5	6.4	7.8
28483.5	10.0	14.3	12.0	17.4	21.1	2.9	7.0	11.9	7.5	14.1
29235.8	3.8	7.8	13.7	8.7	16.2	2.4	1.3	4.6	2.7	5.4
30033.8	3.5	2.6	5.7	4.3	7.2	2.3	1.7	4.7	2.8	5.5
30101.5	2.4	1.8	4.8	2.9	5.7	1.9	1.2	2.2	2.2	3.1
31081.5	3.3	2.8	3.5	4.4	5.6	2.2	2.0	2.7	3.0	4.0
31092.3	2.2	2.0	2.7	3.0	4.0	1.8	1.9	2.6	2.6	3.7
31347.9	2.2	2.3	3.0	3.1	4.4	1.8	1.5	1.3	2.3	2.7
32921.7	4.3	4.1	3.9	5.9	7.1	2.5	3.2	2.8	4.1	4.9
33086.6	2.7	3.5	3.1	4.4	5.4	2.0	1.4	1.7	2.4	3.0
33287.7	2.3	1.6	2.0	2.8	3.5	1.8	1.3	1.8	2.2	2.8
33579.5	2.2	1.7	2.2	2.8	3.6	1.8	1.7	1.2	2.4	2.7
35087.0	4.1	4.1	3.6	5.8	6.8	2.4	3.6	2.2	4.3	4.9
35650.8	3.2	4.5	3.1	5.6	6.3	2.2	2.4	1.5	3.3	3.6
36274.4	3.1	3.3	2.5	4.6	5.2	2.2	2.9	2.2	3.6	4.2
36684.5	2.7	3.5	2.8	4.4	5.3	2.0	2.9	2.8	3.6	4.5
37753.9	3.6	4.6	4.6	5.8	7.4	2.3	3.2	1.5	4.0	4.2
38342.1	3.2	4.2	2.3	5.2	5.7	2.2	2.8	1.7	3.5	3.9

38407.8	2.3	2.9	1.8	3.6	4.1	1.8	2.8	1.3	3.3	3.6
38528.1	2.0	3.0	1.5	3.6	3.9	1.6	1.3	1.3	2.1	2.5
38621.5	1.8	1.4	1.4	2.3	2.7	1.5	1.3	1.1	2.0	2.3
41548.5	6.5	6.3	6.2	9.1	11.0	2.7	1.5	6.2	3.1	6.9
43486.2	5.7	4.4	10.3	7.2	12.6	2.7	2.6	8.9	3.7	9.6
43890.5	3.2	3.2	9.7	4.5	10.7	2.2	1.9	1.7	2.9	3.3
44526.2	3.0	2.8	2.5	4.2	4.9	2.1	2.7	1.8	3.5	3.9
44570.7	2.2	2.8	1.8	3.6	4.0	1.8	1.3	1.5	2.2	2.7
44571.7	1.8	1.3	1.5	2.2	2.7	1.5	1.0	1.5	1.8	2.3
44844.3	1.9	1.4	1.9	2.4	3.0	1.6	1.1	1.7	1.9	2.6
45195.9	2.1	1.6	2.3	2.7	3.5	1.7	1.1	2.2	2.1	3.0
45464.5	2.1	1.6	2.6	2.6	3.7	1.7	1.6	1.3	2.3	2.7
45737.0	2.2	2.0	1.7	2.9	3.4	1.7	1.9	1.3	2.6	2.9
45829.7	1.9	2.1	1.4	2.8	3.1	1.6	1.3	1.4	2.0	2.5
48863.6	6.9	6.5	6.8	9.5	11.7	2.8	1.5	6.7	3.1	7.4
48940.9	2.8	1.6	6.9	3.3	7.6	2.1	1.1	6.1	2.3	6.5
49879.6	3.4	2.5	7.9	4.2	8.9	2.2	1.3	7.8	2.6	8.2
50135.9	2.5	1.7	8.3	3.1	8.9	2.0	1.7	1.8	2.6	3.2
50359.3	2.3	2.0	2.1	3.0	3.7	1.8	1.3	1.7	2.2	2.8
51188.8	3.0	2.6	2.9	4.0	4.9	2.1	1.6	2.5	2.7	3.7
51304.8	2.3	1.8	2.7	2.9	4.0	1.8	1.8	1.6	2.5	3.0
52505.7	3.7	3.7	3.4	5.2	6.2	2.3	2.8	2.0	3.6	4.1
52505.7	2.3	2.8	2.3	3.6	4.1	1.8	2.7	1.8	3.3	3.8
52648.2	2.0	2.9	2.1	3.6	4.1	1.7	1.4	1.7	2.2	2.8
52652.9	1.7	1.4	1.7	2.2	2.8	1.5	1.2	1.1	1.9	2.2
54806.8	4.9	4.6	4.7	6.8	8.2	2.6	2.7	4.0	3.7	5.5
56986.2	6.1	6.3	8.1	8.7	11.9	2.7	2.7	4.9	3.8	6.2
59446.7	6.6	7.0	9.4	9.6	13.5	2.7	4.0	4.1	4.9	6.4
60152.7	3.7	5.2	5.2	6.4	8.2	2.3	1.7	3.8	2.9	4.8
62391.7	5.9	5.2	7.9	7.9	11.1	2.7	5.1	3.3	5.7	6.6
62395.6	2.7	5.1	3.3	5.7	6.6	2.0	1.7	2.1	2.6	3.3
62795.7	2.5	2.2	2.6	3.3	4.2	1.9	1.6	2.6	2.5	3.6
66026.2	7.6	7.2	8.3	10.4	13.3	2.8	7.1	1.7	7.7	7.8
66101.9	2.9	7.3	1.7	7.8	8.0	2.1	4.8	1.7	5.2	5.5
67501.6	4.1	7.1	3.8	8.2	9.0	2.4	7.1	2.5	7.5	7.9
71575.4	9.9	16.0	9.6	18.8	21.2	2.9	13.8	2.2	14.1	14.3
72327.7	3.8	15.6	3.3	16.1	16.4	2.4	3.8	2.9	4.5	5.4
73125.7	3.5	4.7	4.2	5.8	7.2	2.3	4.5	2.3	5.0	5.5
73193.4	2.4	4.6	2.4	5.1	5.7	1.9	1.7	1.8	2.5	3.1
74173.4	3.3	3.1	3.3	4.6	5.6	2.2	3.1	1.4	3.8	4.0
74184.2	2.2	3.1	1.4	3.8	4.1	1.8	3.1	1.0	3.6	3.7
74439.8	2.2	3.5	1.4	4.1	4.4	1.8	1.4	1.4	2.3	2.7

76013.6	4.3	4.0	4.0	5.9	7.1	2.5	4.0	1.6	4.7	4.9
76178.5	2.7	4.3	1.9	5.0	5.4	2.0	1.6	1.5	2.6	3.0
76379.6	2.3	1.9	1.8	2.9	3.5	1.8	1.9	1.2	2.6	2.8
76671.4	2.2	2.3	1.6	3.2	3.6	1.8	1.4	1.5	2.3	2.7
78178.9	4.1	3.8	3.9	5.6	6.8	2.4	3.7	2.1	4.4	4.9
78742.7	3.2	4.6	2.9	5.6	6.3	2.2	1.5	2.5	2.7	3.6
79366.3	3.1	2.3	3.5	3.9	5.2	2.2	1.3	3.4	2.5	4.2
79776.4	2.7	1.9	4.1	3.3	5.3	2.0	1.2	3.9	2.4	4.5
80845.8	3.6	2.9	5.7	4.7	7.4	2.3	2.5	2.5	3.4	4.2
81434.0	3.2	3.5	3.3	4.7	5.7	2.2	1.4	2.9	2.6	3.9
81499.7	2.3	1.5	3.0	2.7	4.1	1.8	1.4	2.8	2.3	3.6
81620.0	2.0	1.5	2.9	2.5	3.9	1.6	1.2	1.4	2.0	2.5
81713.4	1.8	1.3	1.5	2.2	2.7	1.5	1.3	1.1	2.0	2.3
84640.4	6.5	6.3	6.2	9.1	11.0	2.7	5.0	3.9	5.7	6.9

T1,T2,T3 = 10.0 10.0 10.0
W = 5.00E-02
SN,SV,SU = 3.00E+00 5.00E-02 1.60E-05
H = 19300.0

T	S1	S2	S3	PS	RS	T1	T2	T3	PT	RT
0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	10.0	14.1	17.3
394.3	22.1	22.1	22.1	31.3	38.3	3.0	13.7	17.4	14.0	22.4
798.6	10.7	26.5	32.9	28.6	43.6	2.9	8.7	4.7	9.2	10.3
1434.3	8.1	21.5	14.1	22.9	26.9	2.8	21.4	11.1	21.6	24.3
1478.8	3.0	22.3	11.6	22.5	25.3	2.1	1.9	1.4	2.9	3.2
1479.8	2.1	1.9	1.4	2.9	3.2	1.7	1.6	1.3	2.4	2.7
1752.4	2.5	2.4	2.0	3.5	4.0	1.9	1.8	2.0	2.6	3.3
2104.0	2.8	2.7	3.1	3.9	5.0	2.1	2.7	2.1	3.4	4.0
2372.6	2.7	3.4	2.7	4.3	5.1	2.0	1.6	1.5	2.6	3.0
2645.1	2.5	2.1	2.0	3.3	3.9	1.9	2.0	1.5	2.8	3.2
2737.8	2.1	2.1	1.7	3.0	3.4	1.7	1.6	1.1	2.4	2.6
5771.7	7.1	6.8	5.9	9.8	11.5	2.8	5.2	4.4	5.9	7.3
5849.0	2.8	5.3	4.5	6.0	7.5	2.1	5.0	3.5	5.4	6.4
6787.7	3.1	6.3	4.7	7.0	8.4	2.2	6.1	4.5	6.4	7.9
7044.1	2.4	6.4	4.9	6.9	8.4	1.9	2.0	1.3	2.8	3.0
7267.4	2.1	2.3	1.5	3.1	3.5	1.7	1.4	1.5	2.2	2.7
8096.9	2.7	2.3	2.5	3.5	4.3	2.0	2.3	1.3	3.1	3.3
8213.0	2.1	2.5	1.5	3.2	3.6	1.7	1.9	1.2	2.5	2.8
9413.8	3.1	3.2	2.6	4.4	5.1	2.1	1.4	2.6	2.5	3.6
9413.8	2.1	1.4	2.6	2.5	3.6	1.7	1.0	2.6	2.0	3.3
9556.3	1.9	1.2	2.7	2.3	3.6	1.6	1.1	1.7	1.9	2.6

9561.0	1.6	1.1	1.7	2.0	2.6	1.4	1.0	1.2	1.7	2.1
11714.9	3.8	3.5	3.7	5.2	6.4	2.4	3.5	1.4	4.3	4.5
13894.3	4.7	6.2	3.8	7.8	8.7	2.5	2.3	3.8	3.4	5.1
16354.8	5.1	4.8	6.7	7.1	9.7	2.6	4.3	1.5	5.0	5.2
17060.8	3.3	5.1	2.3	6.0	6.4	2.2	3.3	1.7	4.0	4.3
19299.8	4.6	5.7	4.2	7.3	8.4	2.5	4.3	2.1	5.0	5.4
19303.7	2.5	4.3	2.1	5.0	5.4	1.9	2.3	1.1	3.0	3.2
19703.8	2.3	2.7	1.6	3.6	3.9	1.8	2.6	1.2	3.2	3.4
22934.3	5.4	6.2	4.9	8.2	9.6	2.6	3.7	3.9	4.6	6.0
23010.0	2.7	3.8	4.0	4.7	6.1	2.0	3.4	2.7	4.0	4.8
24409.7	3.4	4.9	4.1	6.0	7.2	2.3	4.7	3.6	5.2	6.3
28483.5	6.9	9.6	8.2	11.9	14.4	2.8	4.9	8.2	5.6	9.9
29235.8	3.5	5.5	9.1	6.5	11.2	2.3	1.3	4.1	2.6	4.8
30033.8	3.1	2.2	4.9	3.8	6.1	2.1	1.6	4.3	2.6	5.0
30101.5	2.2	1.6	4.3	2.7	5.1	1.8	1.1	2.1	2.1	3.0
31081.5	2.8	2.4	3.1	3.7	4.8	2.1	1.7	2.4	2.7	3.6
31092.3	2.1	1.7	2.4	2.7	3.6	1.7	1.6	2.3	2.3	3.3
31347.9	2.0	1.9	2.6	2.8	3.8	1.7	1.4	1.3	2.2	2.5
32921.7	3.4	3.3	3.1	4.7	5.6	2.3	2.6	2.3	3.5	4.2
33086.6	2.4	2.8	2.5	3.7	4.5	1.9	1.3	1.6	2.3	2.8
33287.7	2.1	1.6	1.9	2.6	3.2	1.7	1.3	1.7	2.1	2.7
33579.5	2.0	1.6	2.0	2.6	3.3	1.7	1.6	1.2	2.3	2.6
35087.0	3.4	3.3	3.0	4.7	5.5	2.2	2.9	1.9	3.7	4.1
35650.8	2.8	3.5	2.5	4.5	5.2	2.1	2.2	1.5	3.0	3.4
36274.4	2.7	2.9	2.2	4.0	4.5	2.0	2.5	1.9	3.2	3.7
36684.5	2.4	2.9	2.3	3.8	4.5	1.9	2.5	2.3	3.1	3.9
37753.9	3.0	3.6	3.5	4.7	5.9	2.1	2.8	1.4	3.5	3.8
38342.1	2.8	3.4	2.1	4.4	4.8	2.0	2.5	1.6	3.2	3.6
38407.8	2.1	2.6	1.7	3.3	3.7	1.7	2.5	1.2	3.1	3.3
38528.1	1.9	2.7	1.4	3.2	3.5	1.6	1.3	1.2	2.0	2.4
38621.5	1.7	1.4	1.3	2.2	2.6	1.5	1.3	1.1	1.9	2.2
41548.5	4.8	4.6	4.5	6.6	8.0	2.5	1.4	4.5	2.9	5.4
43486.2	4.6	3.5	6.9	5.8	9.0	2.5	2.0	6.2	3.2	7.0
43890.5	2.9	2.4	6.7	3.8	7.7	2.1	1.7	1.7	2.7	3.2
44526.2	2.7	2.4	2.3	3.7	4.3	2.0	2.4	1.6	3.1	3.5
44570.7	2.1	2.4	1.7	3.2	3.6	1.7	1.3	1.4	2.1	2.6
44571.7	1.7	1.3	1.5	2.1	2.6	1.5	1.0	1.4	1.8	2.3
44844.3	1.8	1.3	1.7	2.2	2.8	1.5	1.0	1.6	1.9	2.5
45195.9	1.9	1.5	2.0	2.5	3.2	1.6	1.1	2.0	1.9	2.8
45464.5	1.9	1.4	2.3	2.4	3.3	1.6	1.4	1.3	2.2	2.5
45737.0	1.9	1.8	1.6	2.6	3.1	1.6	1.7	1.2	2.4	2.6
45829.7	1.7	1.8	1.3	2.5	2.8	1.5	1.2	1.3	1.9	2.3

9561.0	1.6	1.1	1.7	2.0	2.6	1.4	1.0	1.2	1.7	2.1
11714.9	3.8	3.5	3.7	5.2	6.4	2.4	3.5	1.4	4.3	4.5
13894.3	4.7	6.2	3.8	7.8	8.7	2.5	2.3	3.8	3.4	5.1
16354.8	5.1	4.8	6.7	7.1	9.7	2.6	4.3	1.5	5.0	5.2
17060.8	3.3	5.1	2.3	6.0	6.4	2.2	3.3	1.7	4.0	4.3
19299.8	4.6	5.7	4.2	7.3	8.4	2.5	4.3	2.1	5.0	5.4
19303.7	2.5	4.3	2.1	5.0	5.4	1.9	2.3	1.1	3.0	3.2
19703.8	2.3	2.7	1.6	3.6	3.9	1.8	2.6	1.2	3.2	3.4
22934.3	5.4	6.2	4.9	8.2	9.6	2.6	3.7	3.9	4.6	6.0
23010.0	2.7	3.8	4.0	4.7	6.1	2.0	3.4	2.7	4.0	4.8
24409.7	3.4	4.9	4.1	6.0	7.2	2.3	4.7	3.6	5.2	6.3
28483.5	6.9	9.6	8.2	11.9	14.4	2.8	4.9	8.2	5.6	9.9
29235.8	3.5	5.5	9.1	6.5	11.2	2.3	1.3	4.1	2.6	4.8
30033.8	3.1	2.2	4.9	3.8	6.1	2.1	1.6	4.3	2.6	5.0
30101.5	2.2	1.6	4.3	2.7	5.1	1.8	1.1	2.1	2.1	3.0
31081.5	2.8	2.4	3.1	3.7	4.8	2.1	1.7	2.4	2.7	3.6
31092.3	2.1	1.7	2.4	2.7	3.6	1.7	1.6	2.3	2.3	3.3
31347.9	2.0	1.9	2.6	2.8	3.8	1.7	1.4	1.3	2.2	2.5
32921.7	3.4	3.3	3.1	4.7	5.6	2.3	2.6	2.3	3.5	4.2
33086.6	2.4	2.8	2.5	3.7	4.5	1.9	1.3	1.6	2.3	2.8
33287.7	2.1	1.6	1.9	2.6	3.2	1.7	1.3	1.7	2.1	2.7
33579.5	2.0	1.6	2.0	2.6	3.3	1.7	1.6	1.2	2.3	2.6
35087.0	3.4	3.3	3.0	4.7	5.5	2.2	2.9	1.9	3.7	4.1
35650.8	2.8	3.5	2.5	4.5	5.2	2.1	2.2	1.5	3.0	3.4
36274.4	2.7	2.9	2.2	4.0	4.5	2.0	2.5	1.9	3.2	3.7
36684.5	2.4	2.9	2.3	3.8	4.5	1.9	2.5	2.3	3.1	3.9
37753.9	3.0	3.6	3.5	4.7	5.9	2.1	2.8	1.4	3.5	3.8
38342.1	2.8	3.4	2.1	4.4	4.8	2.0	2.5	1.6	3.2	3.6
38407.8	2.1	2.6	1.7	3.3	3.7	1.7	2.5	1.2	3.1	3.3
38528.1	1.9	2.7	1.4	3.2	3.5	1.6	1.3	1.2	2.0	2.4
38621.5	1.7	1.4	1.3	2.2	2.6	1.5	1.3	1.1	1.9	2.2
41548.5	4.8	4.6	4.5	6.6	8.0	2.5	1.4	4.5	2.9	5.4
43486.2	4.6	3.5	6.9	5.8	9.0	2.5	2.0	6.2	3.2	7.0
43890.5	2.9	2.4	6.7	3.8	7.7	2.1	1.7	1.7	2.7	3.2
44526.2	2.7	2.4	2.3	3.7	4.3	2.0	2.4	1.6	3.1	3.5
44570.7	2.1	2.4	1.7	3.2	3.6	1.7	1.3	1.4	2.1	2.6
44571.7	1.7	1.3	1.5	2.1	2.6	1.5	1.0	1.4	1.8	2.3
44844.3	1.8	1.3	1.7	2.2	2.8	1.5	1.0	1.6	1.9	2.5
45195.9	1.9	1.5	2.0	2.5	3.2	1.6	1.1	2.0	1.9	2.8
45464.5	1.9	1.4	2.3	2.4	3.3	1.6	1.4	1.3	2.2	2.5
45737.0	1.9	1.8	1.6	2.6	3.1	1.6	1.7	1.2	2.4	2.6
45829.7	1.7	1.8	1.3	2.5	2.8	1.5	1.2	1.3	1.9	2.3

48863.6	5.0	4.7	4.9	6.9	8.4	2.6	1.4	4.8	3.0	5.7
48940.9	2.6	1.5	4.9	3.1	5.8	2.0	1.1	4.6	2.3	5.1
49879.6	3.0	2.2	5.7	3.7	6.8	2.1	1.2	5.7	2.4	6.2
50135.9	2.4	1.6	6.0	2.8	6.6	1.9	1.6	1.8	2.4	3.0
50359.3	2.1	1.8	2.0	2.8	3.4	1.7	1.2	1.6	2.1	2.7
51188.8	2.6	2.2	2.5	3.4	4.3	2.0	1.5	2.2	2.5	3.3
51304.8	2.1	1.6	2.3	2.7	3.5	1.7	1.6	1.5	2.4	2.8
52505.7	3.0	3.0	2.8	4.3	5.1	2.1	2.3	1.7	3.2	3.6
52505.7	2.1	2.3	1.7	3.2	3.6	1.7	2.3	1.6	2.9	3.3
52648.2	1.9	2.4	1.8	3.1	3.5	1.6	1.3	1.5	2.1	2.6
52652.9	1.6	1.4	1.6	2.1	2.6	1.4	1.1	1.1	1.8	2.1
54806.8	3.8	3.6	3.6	5.3	6.4	2.4	2.2	3.1	3.2	4.5
56986.2	4.7	4.6	5.6	6.6	8.6	2.5	2.2	3.8	3.4	5.1
59446.7	5.1	4.9	6.6	7.1	9.7	2.6	3.1	3.3	4.0	5.2
60152.7	3.3	3.9	4.0	5.1	6.4	2.2	1.6	3.3	2.7	4.3
62391.7	4.6	4.0	5.8	6.1	8.4	2.5	4.0	2.7	4.7	5.4
62395.6	2.5	4.0	2.7	4.7	5.4	1.9	1.6	2.0	2.5	3.2
62795.7	2.3	2.0	2.4	3.1	3.9	1.8	1.6	2.4	2.4	3.4
66026.2	5.5	5.2	5.9	7.5	9.6	2.6	5.2	1.6	5.8	6.0
66101.9	2.7	5.2	1.6	5.9	6.1	2.0	4.1	1.6	4.5	4.8
67501.6	3.4	5.6	3.0	6.6	7.2	2.3	5.5	2.1	6.0	6.3
71575.4	6.9	10.8	6.6	12.8	14.4	2.8	9.5	1.8	9.9	10.1
72327.7	3.5	10.5	2.6	11.1	11.4	2.3	3.5	2.5	4.1	4.9
73125.7	3.1	4.1	3.4	5.1	6.2	2.1	4.0	2.1	4.6	5.0
73193.4	2.2	4.1	2.2	4.6	5.1	1.8	1.7	1.7	2.4	3.0
74173.4	2.8	2.7	2.8	3.9	4.8	2.1	2.6	1.3	3.3	3.6
74184.2	2.1	2.6	1.3	3.3	3.6	1.7	2.6	1.0	3.1	3.3
74439.8	2.0	2.9	1.4	3.5	3.8	1.7	1.4	1.3	2.2	2.5
76013.6	3.4	3.2	3.1	4.7	5.6	2.3	3.2	1.5	3.9	4.2
76178.5	2.4	3.4	1.7	4.1	4.5	1.9	1.5	1.5	2.4	2.8
76379.6	2.1	1.8	1.7	2.7	3.2	1.7	1.7	1.1	2.5	2.7
76671.4	2.0	2.1	1.5	2.9	3.3	1.7	1.4	1.4	2.2	2.6
78178.9	3.4	3.1	3.1	4.6	5.5	2.2	3.0	1.8	3.7	4.1
78742.7	2.8	3.6	2.4	4.6	5.2	2.1	1.4	2.2	2.5	3.4
79366.3	2.7	2.1	2.9	3.5	4.5	2.0	1.2	2.9	2.4	3.7
79776.4	2.5	1.7	3.3	3.0	4.5	1.9	1.2	3.2	2.2	3.9
80845.8	3.1	2.5	4.4	3.9	5.9	2.1	2.1	2.2	3.0	3.8
81434.0	2.8	2.8	2.8	3.9	4.8	2.0	1.4	2.6	2.4	3.6
81499.7	2.1	1.4	2.7	2.5	3.7	1.7	1.3	2.5	2.2	3.3
81620.0	1.9	1.4	2.6	2.3	3.5	1.6	1.2	1.3	2.0	2.4
81713.4	1.7	1.3	1.5	2.1	2.6	1.5	1.3	1.1	1.9	2.2
84640.4	4.8	4.6	4.5	6.6	8.0	2.5	3.7	2.9	4.5	5.4

T1,T2,T3 = 10.0 10.0 10.0
W = 5.00E-02
SN,SV,SU = 3.00E+00 1.50E-02 3.20E-05
H = 19300.0

T	S1	S2	S3	PS	RS	T1	T2	T3	PT	RT
0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	10.0	14.1	17.3
394.3	22.1	22.1	22.1	31.3	38.3	3.0	13.7	17.4	14.0	22.4
796.6	10.6	26.5	32.9	28.5	43.6	2.9	8.6	4.7	9.1	10.2
1434.3	7.9	21.3	14.0	22.8	26.7	2.8	21.3	11.0	21.5	24.2
1478.8	2.9	22.2	11.5	22.4	25.2	2.1	1.9	1.3	2.8	3.1
1479.8	2.1	1.9	1.3	2.8	3.1	1.7	1.6	1.2	2.4	2.7
1752.4	2.3	2.2	1.8	3.2	3.7	1.8	1.7	1.8	2.5	3.1
2104.0	2.6	2.5	2.7	3.6	4.5	2.0	2.4	1.9	3.1	3.7
2372.6	2.5	3.0	2.5	3.9	4.6	1.9	1.4	1.4	2.4	2.7
2645.1	2.4	1.8	1.7	3.0	3.4	1.9	1.7	1.3	2.5	2.8
2737.8	2.0	1.8	1.4	2.7	3.0	1.7	1.5	1.0	2.2	2.4
5771.7	6.9	6.4	5.5	9.4	10.9	2.7	4.8	4.0	5.5	6.8
5849.0	2.8	4.9	4.1	5.7	7.0	2.1	4.7	3.3	5.1	6.1
6787.7	2.9	6.1	4.5	6.8	8.2	2.1	5.9	4.4	6.3	7.7
7044.1	2.3	6.4	4.8	6.8	8.3	1.8	1.9	1.2	2.7	2.9
7267.4	2.0	2.1	1.4	2.9	3.2	1.7	1.4	1.4	2.2	2.6
8096.9	2.6	2.1	2.3	3.4	4.0	2.0	2.1	1.3	2.9	3.2
8213.0	2.1	2.3	1.4	3.1	3.4	1.7	1.8	1.1	2.5	2.7
9413.8	3.1	3.3	2.4	4.6	5.2	2.2	1.4	2.4	2.6	3.5
9413.8	2.2	1.4	2.4	2.6	3.5	1.8	1.0	2.4	2.0	3.2
9556.3	1.9	1.1	2.6	2.2	3.4	1.6	1.0	1.7	1.9	2.5
9561.0	1.6	1.0	1.7	1.9	2.5	1.4	.9	1.2	1.7	2.1
11714.9	4.1	3.6	3.8	5.5	6.7	2.4	3.6	1.4	4.4	4.6
13894.3	5.4	7.7	4.1	9.4	10.3	2.6	2.4	4.0	3.6	5.4
16354.8	6.0	5.5	8.6	8.1	11.8	2.7	4.6	1.6	5.4	5.6
17060.8	3.4	5.9	2.2	6.8	7.1	2.2	3.3	1.6	4.0	4.3
19299.8	5.3	6.6	4.8	8.5	9.8	2.6	4.7	2.3	5.4	5.9
19303.7	2.6	4.7	2.3	5.4	5.9	2.0	2.4	1.1	3.1	3.3
19703.8	2.3	2.7	1.4	3.6	3.8	1.8	2.6	1.1	3.2	3.4
22934.3	6.7	7.7	5.8	10.2	11.7	2.7	4.3	4.6	5.1	6.9
23010.0	2.8	4.4	4.7	5.2	7.0	2.0	3.7	2.9	4.2	5.2
24409.7	3.5	5.6	4.7	6.6	8.1	2.3	5.5	4.2	5.9	7.3
28483.5	9.1	13.4	11.0	16.2	19.6	2.8	6.4	10.9	7.0	13.0
29235.8	3.6	7.1	12.6	7.9	14.9	2.3	1.3	4.1	2.6	4.8
30033.8	3.1	2.1	5.0	3.8	6.2	2.2	1.5	4.2	2.6	4.9

30101.5	2.2	1.5	4.3	2.7	5.1	1.8	1.1	2.1	2.1	3.0
31081.5	2.9	2.3	3.1	3.7	4.8	2.1	1.7	2.3	2.7	3.6
31092.3	2.1	1.7	2.4	2.7	3.6	1.7	1.6	2.3	2.3	3.2
31347.9	2.0	1.9	2.6	2.7	3.7	1.6	1.3	1.2	2.1	2.4
32921.7	3.7	3.3	3.2	4.9	5.9	2.3	2.7	2.4	3.6	4.3
33086.6	2.5	2.9	2.6	3.9	4.7	1.9	1.3	1.6	2.3	2.8
33287.7	2.1	1.5	1.8	2.6	3.1	1.7	1.2	1.6	2.1	2.7
33579.5	2.0	1.4	1.9	2.5	3.1	1.7	1.4	1.2	2.1	2.4
35087.0	3.5	3.2	2.9	4.8	5.6	2.3	2.9	1.9	3.7	4.1
35650.8	2.9	3.7	2.5	4.7	5.3	2.1	2.1	1.4	3.0	3.3
36274.4	2.8	2.8	2.0	4.0	4.4	2.0	2.5	1.8	3.2	3.7
36684.5	2.4	2.9	2.3	3.8	4.4	1.9	2.5	2.3	3.1	3.9
37753.9	3.1	3.8	3.8	4.9	6.2	2.2	2.6	1.4	3.4	3.7
38342.1	2.8	3.4	1.9	4.4	4.8	2.1	2.4	1.5	3.2	3.5
38407.8	2.1	2.5	1.5	3.3	3.6	1.7	2.5	1.2	3.0	3.3
38528.1	1.8	2.6	1.3	3.2	3.4	1.6	1.3	1.1	2.0	2.3
38621.5	1.6	1.3	1.2	2.1	2.4	1.4	1.2	1.0	1.9	2.1
41548.5	5.6	5.3	5.1	7.7	9.2	2.6	1.4	5.1	3.0	5.9
43486.2	5.2	3.7	8.9	6.3	11.0	2.6	2.3	7.7	3.4	8.4
43890.5	3.0	2.7	8.4	4.0	9.3	2.1	1.6	1.6	2.7	3.1
44526.2	2.7	2.3	2.1	3.6	4.2	2.0	2.2	1.6	3.0	3.4
44570.7	2.1	2.3	1.6	3.1	3.5	1.7	1.2	1.4	2.1	2.5
44571.7	1.7	1.2	1.4	2.1	2.5	1.5	.9	1.3	1.8	2.2
44844.3	1.7	1.1	1.6	2.0	2.6	1.5	.9	1.5	1.7	2.3
45195.9	1.8	1.2	1.9	2.2	2.9	1.6	1.0	1.8	1.8	2.6
45464.5	1.8	1.2	2.1	2.2	3.1	1.6	1.2	1.2	2.0	2.3
45737.0	1.9	1.5	1.5	2.4	2.8	1.6	1.5	1.1	2.2	2.4
45829.7	1.7	1.6	1.2	2.3	2.6	1.5	1.1	1.2	1.8	2.2
48863.6	6.1	5.5	5.7	8.2	10.0	2.7	1.5	5.7	3.1	6.4
48940.9	2.8	1.5	5.8	3.1	6.6	2.0	1.1	5.3	2.3	5.8
49879.6	2.9	1.9	7.0	3.5	7.8	2.1	1.2	7.0	2.4	7.4
50135.9	2.4	1.4	7.5	2.7	7.9	1.8	1.4	1.8	2.3	2.9
50359.3	2.1	1.6	1.9	2.6	3.2	1.7	1.1	1.5	2.0	2.6
51188.8	2.6	2.0	2.3	3.3	4.0	2.0	1.4	2.1	2.4	3.2
51304.8	2.1	1.5	2.2	2.6	3.4	1.7	1.5	1.4	2.3	2.7
52505.7	3.1	3.0	2.8	4.3	5.2	2.2	2.2	1.7	3.1	3.5
52505.7	2.2	2.2	1.7	3.1	3.5	1.8	2.2	1.5	2.8	3.2
52648.2	1.9	2.3	1.7	3.0	3.4	1.6	1.3	1.4	2.1	2.5
52652.9	1.6	1.3	1.4	2.1	2.5	1.4	1.1	1.0	1.8	2.1
54806.8	4.1	3.7	3.7	5.6	6.7	2.4	2.2	3.2	3.3	4.6
56986.2	5.4	5.3	6.9	7.6	10.2	2.6	2.3	4.1	3.5	5.4
59446.7	6.0	6.0	8.2	8.5	11.8	2.7	3.4	3.5	4.3	5.6

60152.7	3.4	4.4	4.5	5.6	7.1	2.2	1.6	3.3	2.8	4.3
62391.7	5.3	4.4	6.9	6.9	9.7	2.6	4.3	2.9	5.1	5.8
62395.6	2.6	4.3	2.9	5.1	5.9	2.0	1.6	2.1	2.6	3.3
62795.7	2.3	1.9	2.4	3.0	3.8	1.8	1.6	2.4	2.4	3.4
66026.2	6.7	6.2	7.4	9.1	11.7	2.7	6.1	1.6	6.7	6.9
66101.9	2.8	6.2	1.7	6.8	7.0	2.0	4.4	1.6	4.9	5.2
67501.6	3.5	6.6	3.1	7.5	8.1	2.3	6.5	2.3	6.9	7.3
71575.4	9.1	15.2	8.6	17.7	19.6	2.8	12.7	2.1	13.0	13.2
72327.7	3.5	14.4	2.9	14.8	15.1	2.3	3.5	2.4	4.2	4.8
73125.7	3.1	4.1	3.6	5.1	6.2	2.2	3.9	2.1	4.5	4.9
73193.4	2.2	4.0	2.2	4.6	5.1	1.8	1.7	1.7	2.5	3.0
74173.4	2.9	2.7	2.8	3.9	4.8	2.1	2.6	1.3	3.3	3.6
74184.2	2.1	2.6	1.3	3.3	3.6	1.7	2.6	1.0	3.1	3.3
74439.8	2.0	3.0	1.2	3.5	3.7	1.6	1.4	1.2	2.1	2.4
76013.6	3.7	3.4	3.1	5.0	5.9	2.3	3.3	1.5	4.1	4.3
76178.5	2.5	3.6	1.7	4.4	4.7	1.9	1.5	1.4	2.5	2.8
76379.6	2.1	1.7	1.6	2.7	3.1	1.7	1.7	1.1	2.4	2.7
76671.4	2.0	2.0	1.3	2.8	3.1	1.7	1.3	1.2	2.1	2.4
78178.9	3.5	3.1	3.1	4.6	5.6	2.3	2.9	1.8	3.7	4.1
78742.7	2.9	3.8	2.4	4.8	5.3	2.1	1.4	2.1	2.5	3.3
79366.3	2.8	2.0	2.9	3.4	4.4	2.0	1.2	2.8	2.4	3.7
79776.4	2.4	1.5	3.4	2.9	4.4	1.9	1.1	3.2	2.2	3.9
80845.8	3.1	2.3	4.8	3.9	6.2	2.2	2.0	2.2	2.9	3.7
81434.0	2.8	2.8	2.8	4.0	4.8	2.1	1.4	2.5	2.5	3.5
81499.7	2.1	1.4	2.6	2.5	3.6	1.7	1.3	2.4	2.2	3.3
81620.0	1.8	1.4	2.6	2.3	3.4	1.6	1.1	1.3	1.9	2.3
81713.4	1.6	1.1	1.4	2.0	2.4	1.4	1.1	1.1	1.8	2.1
84640.4	5.6	5.2	5.2	7.6	9.2	2.6	4.2	3.2	4.9	5.9

B-19

T1,T2,T3 = 10.0 10.0 10.0
W = 5.00E-02
SN,SV,SU = 3.00E+00 1.50E-02 1.60E-05
H = 19300.0

T	S1	S2	S3	PS	RS	T1	T2	T3	PT	RT
0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	10.0	14.1	17.3
394.3	22.1	22.1	22.1	31.3	38.3	3.0	13.7	17.4	14.0	22.4
798.6	10.6	26.5	32.9	28.5	43.6	2.9	8.6	4.7	9.1	10.2
1434.3	7.9	21.3	14.0	22.7	26.7	2.8	21.3	11.0	21.5	24.2
1478.8	2.9	22.2	11.5	22.4	25.2	2.1	1.9	1.3	2.8	3.1
1479.9	2.1	1.9	1.3	2.8	3.1	1.7	1.6	1.2	2.4	2.7
1752.4	2.3	2.2	1.8	3.2	3.7	1.8	1.7	1.8	2.5	3.1

2104.0	2.6	2.4	2.7	3.5	4.4	2.0	2.4	1.9	3.1	3.6
2372.6	2.4	3.0	2.4	3.8	4.5	1.9	1.4	1.3	2.4	2.7
2645.1	2.3	1.7	1.6	2.9	3.3	1.8	1.6	1.3	2.4	2.7
2737.8	2.0	1.7	1.4	2.6	2.9	1.6	1.4	1.0	2.2	2.4
5771.7	5.8	5.2	4.2	7.8	8.8	2.7	3.9	3.3	4.7	5.7
5849.0	2.7	4.0	3.3	4.8	5.8	2.0	3.9	2.8	4.4	5.2
6787.7	2.6	4.9	3.6	5.6	6.6	2.0	4.8	3.6	5.2	6.3
7044.1	2.1	5.1	3.8	5.5	6.7	1.7	1.8	1.2	2.5	2.7
7267.4	1.9	1.9	1.3	2.6	2.9	1.6	1.3	1.3	2.1	2.4
8096.9	2.1	1.8	1.8	2.7	3.3	1.7	1.8	1.2	2.5	2.7
8213.0	1.8	1.8	1.2	2.6	2.9	1.5	1.5	1.0	2.1	2.4
9413.8	2.4	2.4	1.8	3.3	3.8	1.9	1.3	1.8	2.3	2.9
9413.8	1.9	1.3	1.8	2.3	2.9	1.6	1.0	1.8	1.9	2.6
9556.3	1.7	1.0	1.9	2.0	2.7	1.5	.9	1.4	1.7	2.2
9561.0	1.5	1.0	1.4	1.7	2.2	1.3	.9	1.1	1.6	1.9
11714.9	2.9	2.4	2.6	3.8	4.6	2.1	2.4	1.3	3.2	3.5
13894.3	3.9	4.6	2.9	6.0	6.7	2.4	2.0	2.8	3.1	4.2
16354.8	4.4	3.8	5.3	5.8	7.8	2.5	3.2	1.5	4.1	4.3
17060.8	2.9	3.9	1.8	4.9	5.2	2.1	2.8	1.4	3.5	3.7
19299.8	3.8	4.7	3.1	6.0	6.8	2.3	3.5	1.7	4.2	4.5
19303.7	2.3	3.5	1.7	4.2	4.5	1.8	2.2	1.1	2.9	3.1
19703.8	2.1	2.5	1.3	3.2	3.5	1.7	2.4	1.0	2.9	3.1
22934.3	4.4	5.2	3.6	6.8	7.7	2.5	3.0	3.0	3.9	4.9
23010.0	2.5	3.0	3.0	3.9	4.9	1.9	2.9	2.3	3.5	4.2
24409.7	2.9	4.0	3.4	4.9	5.9	2.1	3.9	3.1	4.4	5.4
28483.5	5.8	8.3	7.0	10.1	12.3	2.7	4.3	6.9	5.1	8.6
29235.8	3.2	4.7	7.8	5.7	9.7	2.2	1.3	3.5	2.5	4.3
30033.8	2.7	1.7	4.1	3.1	5.1	2.0	1.3	3.7	2.4	4.4
30101.5	2.0	1.4	3.7	2.4	4.5	1.7	1.0	2.0	2.0	2.8
31081.5	2.3	1.7	2.6	2.8	3.8	1.8	1.3	2.0	2.3	3.0
31092.3	1.8	1.3	2.0	2.3	3.0	1.6	1.3	1.8	2.0	2.7
31347.9	1.7	1.4	2.0	2.2	3.0	1.5	1.1	1.2	1.9	2.2
32921.7	2.6	2.4	2.3	3.5	4.2	2.0	2.0	1.8	2.8	3.4
33086.6	2.1	2.2	2.0	3.0	3.6	1.7	1.2	1.4	2.1	2.5
33287.7	1.8	1.3	1.6	2.3	2.8	1.6	1.1	1.4	1.9	2.4
33579.5	1.7	1.3	1.6	2.2	2.7	1.5	1.2	1.1	1.9	2.2
35087.0	2.6	2.3	2.1	3.5	4.1	2.0	2.1	1.5	2.9	3.3
35650.8	2.4	2.6	1.9	3.5	4.0	1.9	1.8	1.2	2.6	2.9
36274.4	2.3	2.2	1.6	3.2	3.6	1.8	1.9	1.4	2.7	3.0
36684.5	2.1	2.2	1.7	3.1	3.5	1.7	1.9	1.7	2.6	3.1
37753.9	2.4	2.7	2.5	3.6	4.4	1.9	2.1	1.2	2.8	3.1
38342.1	2.3	2.5	1.6	3.4	3.8	1.8	2.1	1.3	2.8	3.1

38407.8	1.9	2.1	1.4	2.8	3.1	1.6	2.1	1.1	2.6	2.9
38528.1	1.6	2.2	1.1	2.7	3.0	1.4	1.2	1.0	1.9	2.2
38621.5	1.5	1.3	1.1	2.0	2.2	1.3	1.1	.9	1.8	2.0
41543.5	3.6	3.4	3.2	5.0	5.9	2.3	1.4	3.2	2.7	4.2
43486.2	3.9	2.7	5.2	4.7	7.0	2.4	1.7	4.7	2.9	5.6
43890.5	2.6	1.9	5.2	3.2	6.1	2.0	1.5	1.6	2.5	2.9
44526.2	2.4	1.9	1.9	3.0	3.5	1.9	1.8	1.4	2.6	2.9
44570.7	1.9	1.8	1.4	2.6	3.0	1.6	1.1	1.3	2.0	2.4
44571.7	1.6	1.1	1.3	2.0	2.4	1.4	.9	1.3	1.7	2.1
44844.3	1.5	1.0	1.4	1.9	2.3	1.4	.9	1.3	1.6	2.1
45195.9	1.6	1.1	1.5	1.9	2.4	1.4	.9	1.5	1.6	2.2
45464.5	1.5	1.0	1.7	1.9	2.5	1.4	1.0	1.1	1.7	2.0
45737.0	1.5	1.2	1.3	1.9	2.3	1.4	1.2	1.0	1.8	2.1
45829.7	1.4	1.2	1.1	1.9	2.2	1.3	1.0	1.1	1.6	1.9
48863.6	3.8	3.5	3.6	5.2	6.3	2.4	1.4	3.6	2.7	4.5
48940.9	2.4	1.4	3.6	2.8	4.6	1.9	1.0	3.5	2.2	4.1
49879.6	2.5	1.5	4.5	2.9	5.4	1.9	1.1	4.5	2.2	5.0
50135.9	2.1	1.2	4.8	2.4	5.3	1.7	1.2	1.7	2.1	2.7
50359.3	1.8	1.3	1.8	2.3	2.9	1.6	1.0	1.5	1.9	2.4
51188.8	2.1	1.5	1.9	2.6	3.2	1.7	1.2	1.7	2.1	2.7
51304.8	1.8	1.3	1.8	2.2	2.8	1.5	1.3	1.3	2.0	2.4
52505.7	2.4	2.1	2.0	3.2	3.8	1.9	1.7	1.4	2.5	2.9
52505.7	1.9	1.7	1.4	2.5	2.9	1.6	1.6	1.2	2.3	2.6
52648.2	1.7	1.7	1.3	2.4	2.7	1.5	1.2	1.2	1.9	2.2
52652.9	1.5	1.2	1.2	1.9	2.2	1.3	1.0	.9	1.7	1.9
54806.8	2.9	2.6	2.5	3.9	4.6	2.1	1.7	2.2	2.7	3.4
56986.2	3.9	3.4	4.2	5.2	6.7	2.4	1.8	2.9	3.0	4.2
59446.7	4.4	3.8	5.2	5.8	7.8	2.5	2.4	2.6	3.4	4.3
60152.7	2.9	3.0	3.1	4.2	5.2	2.1	1.5	2.7	2.6	3.7
62391.7	3.8	3.1	4.7	4.9	6.7	2.3	3.1	2.4	3.9	4.5
62395.6	2.4	3.1	2.4	3.9	4.5	1.9	1.5	2.0	2.4	3.1
62795.7	2.1	1.7	2.2	2.7	3.5	1.7	1.4	2.2	2.2	3.1
66026.2	4.4	4.0	4.8	5.9	7.7	2.5	3.9	1.5	4.6	4.9
66101.9	2.5	4.0	1.5	4.7	4.9	1.9	3.4	1.4	3.9	4.2
67501.6	2.9	4.7	2.2	5.5	5.9	2.1	4.7	1.8	5.1	5.4
71575.4	5.8	9.5	5.3	11.1	12.3	2.7	8.1	1.7	8.6	8.7
72327.7	3.1	9.1	2.1	9.6	9.8	2.2	3.1	2.0	3.8	4.3
73125.7	2.6	3.5	2.6	4.4	5.1	2.0	3.4	1.9	4.0	4.4
73193.4	2.0	3.5	1.9	4.0	4.5	1.7	1.6	1.6	2.3	2.8
74173.4	2.3	2.1	2.2	3.1	3.8	1.8	2.0	1.3	2.7	3.0
74184.2	1.8	2.0	1.3	2.7	3.0	1.6	2.0	1.0	2.5	2.7
74439.8	1.7	2.2	1.1	2.8	3.0	1.5	1.3	1.1	1.9	2.2

76013.6	2.6	2.4	2.2	3.6	4.2	2.0	2.4	1.3	3.1	3.4
76178.5	2.1	2.6	1.4	3.3	3.6	1.7	1.4	1.3	2.2	2.5
76379.6	1.8	1.5	1.4	2.4	2.8	1.6	1.5	1.0	2.2	2.4
76671.4	1.7	1.7	1.2	2.4	2.7	1.5	1.2	1.1	1.9	2.2
78178.9	2.6	2.3	2.2	3.4	4.1	2.0	2.2	1.5	2.9	3.3
78742.7	2.4	2.6	1.8	3.5	4.0	1.9	1.3	1.7	2.3	2.9
79366.3	2.3	1.7	2.2	2.8	3.6	1.8	1.1	2.1	2.1	3.0
79776.4	2.1	1.3	2.5	2.5	3.5	1.7	1.0	2.4	2.0	3.1
80845.8	2.4	1.7	3.3	3.0	4.4	1.9	1.5	1.9	2.4	3.1
81434.0	2.3	2.0	2.2	3.0	3.7	1.8	1.2	2.1	2.2	3.1
81499.7	1.9	1.3	2.2	2.2	3.1	1.6	1.1	2.1	1.9	2.9
81620.0	1.7	1.2	2.2	2.0	3.0	1.4	1.0	1.3	1.8	2.2
81713.4	1.5	1.0	1.3	1.8	2.2	1.3	1.0	1.0	1.7	2.0
84640.4	3.6	3.3	3.2	4.9	5.9	2.3	2.7	2.2	3.5	4.2

T1,T2,T3 =   360.0   360.0   360.0
W =   5.00E-02
SN,SV,SU =   3.00E+00   5.00E-02   1.60E-05
H = 19300.0

B-22

T	S1	S2	S3	PS	RS	T1	T2	T3	PT	RT
0.0	0.0	0.0	0.0	0.0	0.0	360.0	360.0	360.0	509.1	623.5
394.3	360.5	360.5	360.5	509.9	624.5	3.0	222.5	283.7	222.5	360.6
798.6	22.1	224.1	285.2	225.2	363.4	3.0	18.2	9.7	18.5	20.9
1434.3	9.1	47.4	38.3	48.3	61.6	2.8	46.1	23.7	46.2	51.9
1478.8	3.0	48.1	24.7	48.2	54.2	2.1	2.0	1.4	2.9	3.2
1479.8	2.1	2.0	1.4	2.9	3.2	1.7	1.7	1.3	2.4	2.7
1752.4	2.5	2.5	2.1	3.5	4.1	1.9	1.9	2.1	2.7	3.4
2104.0	2.9	2.8	3.2	4.0	5.2	2.1	2.8	2.1	3.5	4.1
2372.6	2.7	3.5	2.8	4.5	5.3	2.0	1.6	1.5	2.6	3.0
2645.1	2.6	2.1	2.0	3.3	3.9	2.0	2.0	1.5	2.8	3.2
2737.8	2.1	2.1	1.7	3.0	3.5	1.7	1.6	1.1	2.4	2.6
5771.7	7.2	6.8	6.0	9.9	11.6	2.8	5.2	4.4	5.9	7.4
5849.0	2.9	5.3	4.5	6.1	7.6	2.1	5.0	3.6	5.4	6.5
6787.7	3.1	6.4	4.7	7.1	8.5	2.2	6.1	4.6	6.5	7.9
7044.1	2.4	6.5	4.9	6.9	8.5	1.9	2.0	1.3	2.8	3.0
7267.4	2.1	2.3	1.5	3.1	3.5	1.7	1.4	1.5	2.2	2.7
8096.9	2.7	2.3	2.5	3.5	4.3	2.0	2.3	1.3	3.1	3.3
8213.0	2.1	2.5	1.5	3.2	3.6	1.7	1.9	1.2	2.5	2.8
9413.8	3.1	3.2	2.6	4.4	5.1	2.1	[illegible]	2.6	2.5	3.6
9413.8	2.1	1.4	2.6	2.5	3.6	1.7	1.0	2.6	2.0	3.3
9556.3	1.9	1.2	2.7	2.3	3.6	1.6	1.1	1.7	1.9	2.6

9561.0	1.6	1.1	1.7	2.0	2.6	1.4	1.0	1.2	1.7	2.1
11714.9	3.8	3.5	3.7	5.2	6.4	2.4	3.5	1.4	4.3	4.5
13894.3	4.7	6.2	3.8	7.8	8.7	2.5	2.3	3.8	3.4	5.1
16354.8	5.1	4.8	6.7	7.1	9.7	2.6	4.3	1.5	5.0	5.2
17060.8	3.3	5.1	2.3	6.0	6.4	2.2	3.3	1.7	4.0	4.3
19299.8	4.6	5.7	4.2	7.3	8.4	2.5	4.3	2.1	5.0	5.4
19303.7	2.5	4.3	2.1	5.0	5.4	1.9	2.3	1.1	3.0	3.2
19703.8	2.3	2.7	1.6	3.6	3.9	1.8	2.6	1.2	3.2	3.4
22934.3	5.4	6.2	4.9	8.2	9.6	2.6	3.7	3.9	4.6	6.0
23010.0	2.7	3.8	4.0	4.7	6.1	2.0	3.4	2.7	4.0	4.8
24409.7	3.4	4.9	4.1	6.0	7.2	2.3	4.7	3.6	5.2	6.3
28483.5	6.9	9.6	8.2	11.9	14.4	2.8	4.9	8.2	5.6	9.9
29235.8	3.5	5.5	9.1	6.5	11.2	2.3	1.3	4.1	2.6	4.8
30033.8	3.1	2.2	4.9	3.8	6.1	2.1	1.6	4.3	2.6	5.0
30101.5	2.2	1.6	4.3	2.7	5.1	1.8	1.1	2.1	2.1	3.0
31081.5	2.8	2.4	3.1	3.7	4.8	2.1	1.7	2.4	2.7	3.6
31092.3	2.1	1.7	2.4	2.7	3.6	1.7	1.6	2.3	2.3	3.3
31347.9	2.0	1.9	2.6	2.8	3.8	1.7	1.4	1.3	2.2	2.5
32921.7	3.4	3.3	3.1	4.7	5.6	2.3	2.6	2.3	3.5	4.2
33086.6	2.4	2.8	2.5	3.7	4.5	1.9	1.3	1.6	2.3	2.8
33287.7	2.1	1.6	1.9	2.6	3.2	1.7	1.3	1.7	2.1	2.7
33579.5	2.0	1.6	2.0	2.6	3.3	1.7	1.6	1.2	2.3	2.6
35087.0	3.4	3.3	3.0	4.7	5.5	2.2	2.9	1.9	3.7	4.1
35650.8	2.8	3.5	2.5	4.5	5.2	2.1	2.2	1.5	3.0	3.4
36274.4	2.7	2.9	2.2	4.0	4.5	2.0	2.5	1.9	3.2	3.7
36684.5	2.4	2.9	2.3	3.8	4.5	1.9	2.5	2.3	3.1	3.9
37753.9	3.0	3.6	3.5	4.7	5.9	2.1	2.8	1.4	3.5	3.8
38342.1	2.8	3.4	2.1	4.4	4.8	2.0	2.5	1.6	3.2	3.6
38407.8	2.1	2.6	1.7	3.3	3.7	1.7	2.5	1.2	3.1	3.3
38528.1	1.9	2.7	1.4	3.2	3.5	1.6	1.3	1.2	2.0	2.4
38621.5	1.7	1.4	1.3	2.2	2.6	1.5	1.3	1.1	1.9	2.2
41548.5	4.8	4.6	4.5	6.6	8.0	2.5	1.4	4.5	2.9	5.4
43486.2	4.6	3.5	6.9	5.8	9.0	2.5	2.0	6.2	3.2	7.0
43890.5	2.9									

T1,T2,T3 =   10.0   10.0   10.0

W =   1.00E-01
SN,SV,SU =   3.00E+00   5.00E-02   1.60E-05
H = 19300.0

T	S1	S2	S3	PS	RS	T1	T2	T3	PT	RT
0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	10.0	14.1	17.3
394.3	40.7	40.7	40.7	57.5	70.5	3.0	25.1	32.0	25.3	40.8

798.6	11.7	50.4	63.7	51.7	82.0	2.9	9.4	5.1	9.9	11.1
1434.3	8.2	23.3	15.1	24.7	29.0	2.8	23.3	12.1	23.5	26.4
1478.8	3.0	24.3	12.6	24.5	27.5	2.1	1.9	1.4	2.9	3.2
1479.8	2.1	1.9	1.4	2.9	3.2	1.7	1.6	1.3	2.4	2.7
1752.4	2.5	2.4	2.0	3.5	4.0	1.9	1.8	2.0	2.6	3.3
2104.0	2.8	2.7	3.1	3.9	5.0	2.1	2.7	2.1	3.4	4.0
2372.6	2.7	3.4	2.7	4.3	5.1	2.0	1.6	1.5	2.6	3.0
2645.1	2.6	2.1	2.0	3.3	3.9	1.9	2.0	1.5	2.8	3.2
2737.8	2.1	2.1	1.7	3.0	3.4	1.7	1.6	1.1	2.4	2.6
5771.7	7.1	6.8	5.9	9.8	11.5	2.8	5.2	4.4	5.9	7.3
5849.0	2.8	5.3	4.5	6.0	7.5	2.1	5.0	3.5	5.4	6.4
6787.7	3.1	6.3	4.7	7.0	8.4	2.2	6.1	4.5	6.4	7.9
7044.1	2.4	6.4	4.9	6.9	8.4	1.9	2.0	1.3	2.8	3.0
7267.4	2.1	2.3	1.5	3.1	3.5	1.7	1.4	1.5	2.2	2.7
8096.9	2.7	2.3	2.5	3.5	4.3	2.0	2.3	1.3	3.1	3.3
8213.0	2.1	2.5	1.5	3.2	3.6	1.7	1.9	1.2	2.5	2.8
9413.8	3.1	3.2	2.6	4.4	5.1	2.1	1.4	2.6	2.5	3.6
9413.8	2.1	1.4	2.6	2.5	3.6	1.7	1.0	2.6	2.0	3.3
9556.3	1.[illegible]	1.2	2.7	2.3	3.6	1.6	1.1	1.7	1.9	2.6
9561.0	1.8	1.1	1.7	2.0	2.6	1.4	1.0	1.2	1.7	2.1
11714.9	3.8	3.5	3.7	5.2	6.4	2.4	3.5	1.4	4.3	4.5
13894.3	4.7	6.2	3.8	7.8	8.7	2.5	2.3	3.8	3.4	5.1
16354.8	5.1	4.8	6.7	7.1	9.7	2.6	4.3	1.5	5.0	5.2
17060.8	3.3	5.1	2.3	6.0	6.4	2.2	3.3	1.7	4.0	4.3
19299.8	4.6	5.7	4.2	7.3	8.4	2.5	4.3	2.1	5.0	5.4
19303.7	2.5	4.3	2.1	5.0	5.4	1.9	2.3	1.1	3.0	3.2
19703.8	2.3	2.7	1.6	3.6	3.9	1.8	2.6	1.2	3.2	3.4
22934.3	5.4	6.2	4.9	8.2	9.6	2.6	3.7	3.9	4.6	6.0
23010.0	2.7	3.8	4.0	4.7	6.1	2.0	3.4	2.7	4.0	4.8
24409.7	3.4	4.9	4.1	6.0	7.2	2.3	4.7	3.6	5.2	6.3
28483.5	6.9	9.6	8.2	11.9	14.4	2.8	4.9	8.2	5.6	9.9
29235.8	3.5	5.5	9.1	6.5	11.2	2.3	1.3	4.1	2.6	4.8
30033.8	3.1	2.2	4.9	3.8	6.1	2.1	1.6	4.3	2.6	5.0
30101.5	2.2	1.6	4.3	2.7	5.1	1.8	1.1	2.1	2.1	3.0
31081.5	2.8	2.4	3.1	3.7	4.8	2.1	1.7	2.4	2.7	3.6
31092.3	2.1	1.7	2.4	2.7	3.6	1.7	1.6	2.3	2.3	3.3
31347.9	2.0	1.9	2.6	2.8	3.8	1.7	1.4	1.3	2.2	2.5
32921.7	3.4	3.3	3.1	4.7	5.6	2.3	2.6	2.3	3.5	4.2
33086.6	2.4	2.8	2.5	3.7	4.5	1.9	1.3	1.6	2.3	2.8
33287.7	2.1	1.6	1.9	2.6	3.2	1.7	1.3	1.7	2.1	2.7
33579.5	2.0	1.6	2.0	2.6	3.3	1.7	1.6	1.2	2.3	2.6
35087.0	3.4	3.3	3.0	4.7	5.5	2.2	2.9	1.9	3.7	4.1

35650.8	2.8	3.5	2.5	4.5	5.2	2.1	2.2	1.5	3.0	3.4
36274.4	2.7	2.9	2.2	4.0	4.5	2.0	2.5	1.9	3.2	3.7
36684.5	2.4	2.9	2.3	3.8	4.5	1.9	2.5	2.3	3.1	3.9
37753.9	3.0	3.6	3.5	4.7	5.9	2.1	2.8	1.4	3.5	3.8
38342.1	2.8	3.4	2.1	4.4	4.8	2.0	2.5	1.6	3.2	3.6
38407.8	2.1	2.6	1.7	3.3	3.7	1.7	2.5	1.2	3.1	3.3
38528.1	1.9	2.7	1.4	3.2	3.5	1.6	1.3	1.2	2.0	2.4
38621.5	1.7	1.4	1.3	2.2	2.6	1.5	1.3	1.1	1.9	2.2
41548.5	4.8	4.6	4.5	6.6	8.0	2.5	1.4	4.5	2.9	5.4
43486.2	4.6	3.5	6.9	5.8	9.0	2.5	2.0	6.2	3.2	7.0
43890.5	2.9									

T1,T2,T3 = 360.0 360.0 360.0

W = 1.00E-01

SN,SV,SU = 3.00E+00 5.00E-02 1.60E-05

H = 19300.0

T	S1	S2	S3	PS	RS	T1	T2	T3	PT	RT
0.0	0.0	0.0	0.0	0.0	0.0	360.0	360.0	360.0	509.1	623.5
394.3	362.2	362.2	362.2	512.2	627.3	3.0	223.5	285.0	223.5	362.2
798.6	41.2	229.7	291.1	233.4	373.1	3.0	36.2	19.1	36.3	41.0
1434.3	9.4	94.2	75.7	94.6	121.2	2.9	91.5	46.9	91.6	102.9
1478.8	3.0	95.5	48.9	95.5	107.3	2.1	2.0	1.4	2.9	3.2
1479.8	2.1	2.0	1.4	2.9	3.2	1.7	1.7	1.3	2.4	2.7
1752.4	2.5	2.5	2.1	3.5	4.1	1.9	1.9	2.1	2.7	3.4
2104.0	2.9	2.8	3.2	4.1	5.2	2.1	2.8	2.1	3.5	4.1
2372.6	2.7	3.5	2.8	4.5	5.3	2.0	1.6	1.5	2.6	3.0
2645.1	2.6	2.1	2.0	3.3	3.9	2.0	2.0	1.5	2.8	3.2
2737.8	2.1	2.1	1.7	3.0	3.5	1.7	1.6	1.1	2.4	2.6
5771.7	7.2	6.8	6.0	9.9	11.6	2.8	5.2	4.4	5.9	7.4
5849.0	2.9	5.4	4.5	6.1	7.6	2.1	5.0	3.6	5.4	6.5
6787.7	3.1	6.4	4.7	7.1	8.5	2.2	6.1	4.6	6.5	7.9
7044.1	2.4	6.5	4.9	6.9	8.5	1.9	2.0	1.3	2.8	3.0
7267.4	2.1	2.3	1.5	3.1	3.5	1.7	1.4	1.5	2.2	2.7
8096.9	2.7	2.3	2.5	3.5	4.3	2.0	2.3	1.3	3.1	3.3
8213.0	2.1	2.5	1.5	3.2	3.6	1.7	1.9	1.2	2.5	2.8
9413.8	3.1	3.2	2.6	4.4	5.1	2.1	1.4	2.6	2.5	3.6
9413.8	2.1	1.4	2.6	2.5	3.6	1.7	1.0	2.6	2.0	3.3
9556.3	1.9	1.2	2.7	2.3	3.6	1.6	1.1	1.7	1.9	2.6
9561.0	1.6	1.1	1.7	2.0	2.6	1.4	1.0	1.2	1.7	2.1
11714.9	3.8	3.5	3.7	5.2	6.4	2.4	3.5	1.4	4.3	4.5
13894.3	4.7	6.2	3.8	7.8	8.7	2.5	2.3	3.8	3.4	5.1
16354.8	5.1	4.8	6.7	7.1	9.7	2.6	4.3	1.5	5.0	5.2

17060.8	3.3	5.1	2.3	6.0	6.4	2.2	3.3	1.7	4.0	4.3
19299.8	4.6	5.7	4.2	7.3	8.4	2.5	4.3	2.1	5.0	5.4
19303.7	2.5	4.3	2.1	5.0	5.4	1.9	2.3	1.1	3.0	3.2
19703.8	2.3	2.7	1.6	3.6	3.9	1.8	2.6	1.2	3.2	3.4
22934.3	5.4	6.2	4.9	8.2	9.6	2.6	3.7	3.9	4.6	6.0
23010.0	2.7	3.8	4.0	4.7	6.1	2.0	3.4	2.7	4.0	4.8
24409.7	3.4	4.9	4.1	6.0	7.2	2.3	4.7	3.6	5.2	6.3
28483.5	6.9	9.6	8.2	11.9	14.4	2.8	4.9	8.2	5.6	9.9
29235.8	3.5	5.5	9.1	6.5	11.2	2.3	1.3	4.1	2.6	4.8
30033.8	3.1	2.2	4.9	3.8	6.1	2.1	1.6	4.3	2.6	5.0
30101.5	2.2	1.6	4.3	2.7	5.1	1.8	1.1	2.1	2.1	3.0
31081.5	2.8	2.4	3.1	3.7	4.8	2.1	1.7	2.4	2.7	3.6
31092.3	2.1	1.7	2.4	2.7	3.6	1.7	1.6	2.3	2.3	3.3
31347.9	2.0	1.9	2.6	2.8	3.8	1.7	1.4	1.3	2.2	2.5
32921.7	3.4	3.3	3.1	4.7	5.6	2.3	2.6	2.3	3.5	4.2
33086.6	2.4	2.8	2.5	3.7	4.5	1.9	1.3	1.6	2.3	2.8
33287.7	2.1	1.6	1.9	2.6	3.2	1.7	1.3	1.7	2.1	2.7
33579.5	2.0	1.6	2.0	2.6	3.3	1.7	1.6	1.2	2.3	2.6
35087.0	3.4	3.3	3.0	4.7	5.5	2.2	2.9	1.9	3.7	4.1
35650.8	2.8	3.5	2.5	4.5	5.2	2.1	2.2	1.5	3.0	3.4
36274.4	2.7	2.9	2.2	4.0	4.5	2.0	2.5	1.9	3.2	3.7
36684.5	2.4	2.9	2.3	3.8	4.5	1.9	2.5	2.3	3.1	3.9
37753.9	3.0	3.6	3.5	4.7	5.9	2.1	2.8	1.4	3.5	3.8
38342.1	2.8	3.4	2.1	4.4	4.8	2.0	2.5	1.6	3.2	3.6
38407.8	2.1	2.6	1.7	3.3	3.7	1.7	2.5	1.2	3.1	3.3
38528.1	1.9	2.7	1.4	3.2	3.5	1.6	1.3	1.2	2.0	2.4
38621.5	1.7	1.4	1.3	2.2	2.6	1.5	1.3	1.1	1.9	2.2
41548.5	4.8	4.6	4.5	6.6	8.0	2.5	1.4	4.5	2.9	5.4
43486.2	4.6	3.5	6.9	5.8	9.0	2.5	2.0	6.2	3.2	7.0